30th International
PLEA Conference

SUSTAINABLE HABITAT FOR DEVELOPING SOCIETIES

Proceedings

December 16 - 18, 2014

2014 plea ahmedabad

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PLEA Conference

SUSTAINABLE HABITAT FOR DEVELOPING SOCIETIES
Choosing the way forward

December 16 -18, 2014

Book of Proceedings

CEPT University

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PLEA 2014 Conference 16-18 December, 2014

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Foreword

Founded in 1981, PLEA (Passive and Low Energy Architecture) is the oldest organisation that has played a pivotal role in bringing Sustainable Architecture to the mainstream. As an autonomous world-wide non-profit network of professionals, academics and students, PLEA International is engaged in a discourse on sustainable architecture and urban design (http://plea-arch.org). PLEA conferences are held annually and address a wide variety of contemporary and imminent themes, relevant to the local hosting regions.

It was with great enthusiasm that the PLEA Board of Directors welcomed the challenge for the 30th PLEA International Conference to be hosted in Ahmedabad and organised by the Centre for Advanced Research in Building Science and Energy, CEPT University. This year's focus on sustainable habitat for developing societies and emerging economies will challenge the urgent need to reduce energy use in new and existing buildings in cities that are witnessing rapid growth and urbanization.

India is today one of the world's fastest growing economies due to industrialisation, urbanisation and economic development together with people's expectations of improved living standards. India's urban landscape is changing at unprecedented rates due to the immense increase in population and migration to its cities. Some cities are expanding and others are being built afresh, while new architectural and urban solutions are being shaped.
Energy consumption in the building sector is very high and it is expected to increase further due to change of life style, typology of the building and climate change. With further growth there is an urgent need to reduce energy use in new and existing buildings in cities.

Hot and dry climates, like those in several Indian regions, encourage greater use of air conditioning system. Today new Indian architecture in India shows an increase number of enclosed, gated communities, glass boxes, high-rise buildings and skyscrapers that produce self-contained environments. Buildings fully dependent on mechanical air-conditioning are still on the rise, with little connection to the outside and no control over individual environmental conditions. We also see a movement towards a globalised, far from locally generated, architecture.

However, we never had so many buildings as before claiming to be "green" or "sustainable", but there is little knowledge about how they performed and about its inhabitants' perspective. Detailed and reliable measurements are quite scarce. We need to know more about how buildings are used and how they adapt to their environment. Labelling and certification can be an indication of certain environmental qualities of a building, but they tell little about how people feel and enjoy living inside it. Measurements and data from surveys while buildings are being occupied are fundamental for architecture to evolve and turn more sustainable. There are many interesting examples out there worth having data about the inhabitants' experiences. It is the only way we designers can learn how well our concepts and our designs are doing.

Concerns over global warming and the need for sustainable development, have led to large investment into the research and development of technologies and design approaches which will reduce our dependency on fossil fuels. The application of these techniques to building projects has spread around the world and is slowly becoming part of the mainstream, but there is a perceived knowledge and skills gap among construction professionals. The global appeal of bioclimatic approach has been promoted worldwide by the PLEA expert network through its international conferences. During the course of the PLEA 2014 conference in Ahmedabad, debates will address various dimensions of architectural and design science to help realising buildings, neighbourhoods and cities that have minimal impact on natural resources whilst satisfying the comfort requirements and aspirations of a fast developing society. Under this central theme, the conference will propose a diverse range of topics to understand the role of architectural practice, research and education towards addressing the issues of energy conservation, efficiency and management through design, construction and operational stages of buildings, neighbourhoods and cities.

Will Indian architectural practices come up with the right vision and lead Asia to move towards a new approach to deal with the challenges of climate change, technological development and urban growth, in an alternative way, less dependent on fossil fuels? I hope the current transformations India is facing are a great opportunity for new moves towards the development of more pleasant cities and sustainable buildings.

I expect that PLEA 2014 is a chance for international and local sharing of current practices, research and knowledge and that the event generates dynamic discussions and innovative approaches to future challenges in architecture and urban design in India and worldwide.

I would like to thank all those who contributed to the elaboration of this book of proceedings: the Organising Team for their relentless dedication during the preparations; the peer reviewers who helped with the challenging task of selecting and reviewing almost 950 abstracts and 380 full papers, providing critical and constructive comments and ensuring scientific quality; and all the authors for their contributions and for sharing their projects and findings without which this book of Proceedings and the 30th PLEA International Conference would not be possible.

Paula Cadima,
President of PLEA

Foreword

'CHOICES WE HAVE, AND CHOICES WE NEED TO MAKE'

The Twentieth century has been a century of 'Consumption', a concern, which a majority of thinkers, decision makers, professionals, activists, and a few leaders of the world have already brought to the forefront. Nonetheless, there is a growing consensus worldwide, that the Twenty-first century needs to be the century of 'Frugality' and 'Responsible Decision Making'. I am convinced that making judicious choices is no longer an option for any of us, irrespective of the nature, the scale, the complexity, or the constraints, of the issues, instead, it must be imbibed in our psyche.

'Information era' as it has also been called, has been marked by an onslaught of unprecedented mass communication tools, decreasing the physical distances, and increasing the range of choices for every conceivable problem or an issue. It appears that technology backed answers or solutions spring up in no time being labeled as 'Innovation' and 'Development'. It is not my argument that these innovations and developments are undesirable, however, the questions is, have these innovative choices, in reality, solved the problems, and resolved the issues, without creating another set of problems and issues? Has the freedom offered by multiple choices at our finger tips, led to improving our decision making processes in the long term interest of the society at large, of our globalized but diverse worlds?

Quite often, I wonder, if the time we consume in taking a decision from the many choices out there, leave us with any time to think about 'how to make a choice'? Does the pace of the growth of the society, and the pressures of making timely decisions leave us with any space for considering, what will be the long term impact, or consequences, of that choice? For any given problem, or an issue, or a situation, do the choices we make reflect a holistic thought process, do they curb the creation of new unforeseen issues to be resolved, or do they just follow the market driven, novelty focused materials, technologies, and innovations? Why are the 'frugal innovations' not seen to be emerging as fast as the prevalent unsustainable scenarios demand them to be?

In my observation, application of the knowledge of the 'Traditional Wisdom' and the freely available 'Common Knowledge & Common Sense' has eluded their use in our decision making processes. The question is, is this by choice, or by default? The 'Traditional Knowledge & Wisdom' needs to be seen as a community asset, which have emerged over centuries of development, and have contributed significantly to make the world far more sustainable than what we find ourselves in today. These appear to have almost disappeared from our choices today, as if they are irrelevant. These applications, however, are not only relevant, but are available and utilised in the fringe & regional pockets of most emerging economies, and need to be taken cognizance of.

PLEA 2014 is the opportunity for all of us to deliberate some of these issues threadbare and explore further the appropriate avenues & directions to make the world we live in more responsible, more sustainable, and of course more livable. This is certainly possible when 164 papers and 65 posters representing 42 countries come together as more than 350 delegates exchange thoughts, ideas, and their divergent views towards a common cause, over three intense days.

It is time to think of the 'Choices we have and Choices we need to make', to become more responsible citizens of the world we intend to leave behind for the coming generations.

Nimish Patel
Chairman PLEA 2014

Widening Horizons and Evolving Practice of Sustainability in India – A Case for Convergence

Ashok B. Lall,
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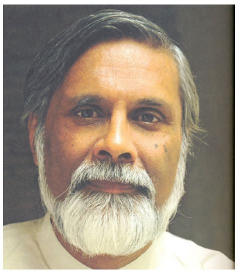

In today's context of a developing economy undergoing rapid urbanization the coming decade will, arguably, be the determining decade for the quality of life and environmental fate of our cities. Over the last decade, with a growing awareness of climate change and environmental sustainability, the professions of the built environment have come to recognize the criticality of the ways in which buildings are to be built and the patterns of urban development that are adopted for the growth of cities. One can see increasing activity at the governmental and institutional levels with a primary focus on Climate Change and, more recently, a concern for protection of the environmental commons and bio-diversity. In this largely science-and-technology approach, which has its roots in the formulation of the sustainability theory in the developed West, what is clearly missing is an understanding of the relationship between sustainable architecture and urbanism in its developmental dimension –as a strategic method for improving the quality of life founded on environmental security, from a platform of limited resources. A more serious concern is the confusion that pervades the culture of architectural practice with respect to sustainability.

This paper attempts to establish the social and environmental context of the present developmental condition in India which the practice of sustainability needs to engage with. It briefly traces the historical processes that have thrown up divergent attitudes to sustainability in the practice of architecture today. It argues for bringing together the various strands of knowledge and practice, and for a theory for the practice of sustainability specific to the situation of the developing South.

Thermal counterpoint in the phenomenology of architecture – A Phsychophysiological explanation of Heschong's 'Thermal Delight'

Prof. Richard de Dear

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Typically about half of a commercial building's energy input is allocated to the pursuit of thermally neutral indoor environments. In developed countries we find ourselves spending more than 90% of our daily lives inside built environments, most of which are now sealed off from the outside world and fully air-conditioned such that their indoor climate typically hovers within a single degree some theoretical optimum - circa 22°C. Yet despite the prodigious energy costs of thermally neutralising buildings, large thermal comfort field-studies consistently report overall levels of occupant thermal satisfaction rarely getting above 80%.

In this paper I'll take another look at Heschong's (1979) eloquent diatribe against thermal neutrality. Using a phenomenological rather than scientific analysis, Heschong's 'Thermal Delight in Architecture' succinctly put the case that architecture was profoundly impoverished when it outsourced to engineers responsibility for the thermal realm of buildings. Heschong contends that, under certain combinations and sequences, the elements of indoor climate can infuse our total sensory experience of space with layers of affect, emotion, even delight, in ways that other dimension of the built environment can't. But these opportunities are squandered when thermal design falls into the hands of those whose stated mission is to neutralise buildings.

Although she didn't know it at the time of writing her book, the phenomenon Heschong describes as thermal delight has a name in contemporary physiology – alliesthesia. It refers to situations in which a given thermal stimulus can be subjectively experienced as either pleasant or unpleasant, depending on whether it is likely to restore or perturb the milieu interior's target set-points. The hallmark of positive alliesthesia is pleasure, which is made available across all our senses through contrast, transience, non-steady-state, light and shadow. So in the thermal context of buildings, the HVAC engineer's design objective of eliminating all thermal sensation from the occupant's experience of the space efficiently precludes thermal delight. When we engineer spatial and temporal thermal uniformity into a space the building ceases to have any physiological significance or meaning for its occupants – thermal affect and hedonics are extinguished when a building is neutralised.

The paper will conclude by illustrating the phenomenon of alliesthesia with Gujarat's architectural treasures. The AdalajStepwell is a magnificent water cistern close to Ahmedabad in the Indian state of Gujarat. Since the structure is five storeys deep, people wishing to draw water from the well experience a pronounced thermocline upon descending from the heat of the sub-continental climate at ground level, down to the luxurious subterranean coolth at water-level. The thermal textures and counterpoint along this trajectory beautifully exemplifies the psychophysiological principle of alliesthesia, reinforcing and amplifying the visual delight of the step-well's carved sandstone with another exquisite delight of the thermal variety, engendering a deeply poetic sense of place.

Keywords: Thermal comfort, isothermal, transient, thermoreceptor, alliesthesia, topophilia, step-well.

Ardeshir Mahdavi, PhD

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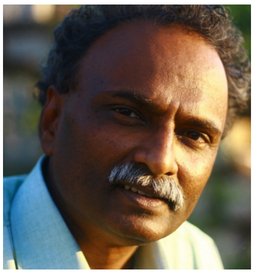
To call cities complex entities would be a major understatement. A multitude of environmental, economical, and social disciplines, approaches, and studies have only started to scratch the surface of intricate life and evolution of structures we call cities. In this context, the present keynote address focuses on the challenging and consequential topic of the urban microclimate. In recent history, cities have grown in number and size, emerging thus as massive anthropogenic interventions in the planetary environment. They contribute to climate change and are affected by it. The urban microclimate with its temporal and spatial variance can significantly influence the performance of buildings and the well-being of the city dwellers. In light of this, there is a critical need for a deeper understanding of the tightly intertwined feedback loops between the local, regional, and global climate and their consequences for urbanism and architecture.



Dr. Chandrashekar Hariharan

Chairperson, ZED Group, Bangalore

'I am my brother's keeper' is shorthand for an ideal self-sacrifice and service to the larger group. If helping your brother is a 'social purpose', then how does one see the bizarre spectacle of individuals, companies, and senior bureaucrats and politicians forcing helpless and mute millions to give up or sacrifice their lands, their forests, their rivers, and to suffer untold misery in the name of helping one's brother? This is not social responsibility.

Can you move from such supply/side thinking, which are insensitive to ecosystems and to their vulnerable people, and move firmly toward demand-side approaches where you tell yourself that the only solution for energy deficiency, is not energy generation, but is energy efficiency.

How do you move from these market-led central solutions for energy, water, and waste and move towards federal and local solutions within your home, neighborhood or office block?

How do you move from central infrastructure to self-reliance with from government agencies for energy, water and waste?

Session 1A : Passive Design

PLEA 2014: Day 1, Tuesday, December 16
11:30 - 13:10, Auditorium - Knowledge Consortium of Gujarat

Effect of Courtyard Height and Proportions on Energy Performance of Multi-Storey Air-Conditioned Desert Buildings.

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ABSTR ACT

Courtyard buildings have been always recommended as a passive architectural technique in desert environments in order to maintain indoor thermal comfort. Nowadays, an increasing number of buildings are air-conditioned. The importance of using passive techniques, then, becomes to reduce energy consumption. A previous study, however, showed that in desert environments, the energy performance of two-storey residential courtyard buildings proved less efficient than other solid forms, even when attached to neighbouring buildings from three sides in a compact urban fabric. Their performance was relatively better in mild desert climates than in extreme hot ones. The study was limited to a single family house with "thin" depth of zones surrounding the courtyard.

In multi-storey courtyard buildings, the courtyard results in more height and self-shading on the facades overlooking the courtyard. This will have a direct effect on the energy consumed for cooling and heating, as well as on that consumed by artificial lighting

This study questions the effect of courtyard height proportions and thickness of the built area surrounding it on the energy consumption in multi-storey air-conditioned courtyard buildings and tracks that effect under different desert climates. Courtyard buildings of 1-10storey-height were modelled using the DesignBuilder software and simulated using EnergyPlus simulation engine for the desert climates of Khargah, Cairo, Alexandria and for the temperate climate of Berlin for comparison. All cases were compared to the corresponding solid building forms of the same built area.

Air-conditioned courtyard houses has not shown a significant improvement in energy savings in desert environments, buildings with bigger depth surrounding the courtyard had a much better performance than thinner buildings, giving small energy savings with building depth exceeding 12m

Keywords: multi-storey courtyard, air-conditioned, desert buildings, energy performance simulation.

INTRODUCTION

Courtyard buildings have been always recommended as a passive architectural technique in desert environments in order to maintain indoor thermal comfort. Nowadays, an increasing number of buildings are air-conditioned. The importance of using passive techniques, then, becomes to reduce energy consumption. A previous study, however, showed that in desert environments, the energy performance of two-storey residential courtyard buildings proved less efficient than other solid forms, even when attached to neighbouring buildings from three sides in a compact urban fabric [1]. Their performance was relatively better in mild desert climates than in extreme hot ones. The study was limited to a single family house with “thin” depth of zones surrounding the courtyard. Neither the effect of change in building depth (BD) surrounding the courtyard was not studied, nor the effect of courtyard height proportions (HP), while both are still questionable.

Review of recent literature demonstrated that the performance of a courtyard as a passive cooling strategy was discussed in numerous publications. The effect of a naturally ventilated courtyard on thermal performance was studied in hot arid, tropical and warm humid tropical climates [2, 3, 4]. Results showed that a courtyard building with controlled natural ventilation, of specified opening time improved thermal performance. However in hot arid climate, the thermal performance resulting from continuous day and night natural ventilation was worse than keeping the building closed without natural ventilation [2].

The shading effect of different courtyard forms [5] and that of courtyard proportions [6] were studied. It was found that in Rome, courtyards with deep proportions were recommended over shallow ones. However, in both studies the tested buildings were solid with no windows, and thus both the effect of transmitted solar radiation and the energy needed for artificial lighting were not considered.

The passive effect of courtyard with plants and water pool on energy consumed for heating and cooling was studied [7]. It was found that passive features alone could not maintain comfort during hot summer times in Tehran, and that similar effects could be obtained through envelope components such as insulation and double glazing. However, the energy needed for artificial lighting that compensates for the effect of shading was not accounted for.

A study of energy performance of courtyard buildings in different climatic conditions showed that better performance was achieved in hot-dry and hot-humid climates rather than in cold and temperate ones [8]. The study was limited to zones overlooking the courtyard and ignored the influence of the external perimeter walls and zones. The impact of integrating deep courtyards in mid-rise housing buildings in Dubai was evaluated, showing that a six-storey courtyard building achieved up to 6.9% savings [9]. The addressed heights ranged from 4 to 10 stories high, while two-storey low-rise residential buildings that are common in some countries like Saudi Arabia were not considered.

Some studies addressed the effect of orientation on thermal performance for non-air-conditioned buildings in a hot-humid tropical climate [10] and the implications of orientation on thermal energy efficiency of passive buildings in mild temperate climate [11].

Literature showed that the combined effect of building depth surrounding the courtyard and the courtyard’s height proportions on energy consumed in heating, cooling and lighting of air-conditioned buildings in the desert needs more investigation.

OBJECTIVES

This research aims at exploring the effect of courtyard on energy consumption of heating, cooling and lighting in air-conditioned multi-storey residential desert buildings based on two parameters: height proportions, and the depth of built area surrounding the courtyard.

METHODOLOGY

Six courtyard buildings with fixed courtyard plan dimensions (12X12m) were tested for energy performance in the following cases of thickness of built area surrounding the courtyard: 4, 6, 8, 10, 12, 20m. Values of thicknesses 14, 16, 18m were interpolated.Each case was tested in building heights of 1,2,4,6,8 and 10 floors. These represented courtyard section length-to-height proportions of 1:0.25, 1:0.5, 1:1, 1:1.5, 1:2, and 1:2.5 respectively. Then, for each of the six main cases, a solid square building of the same built area and height (but with no courtyard) was tested for comparison.

The energy use intensity (EUI) of each of the courtyard BD cases was compared in different HPs in order to detect how the building's height affects the overall energy consumption per square meter. This overall value in each courtyard building case was compared to its corresponding solid square case to detect which form was more efficient in energy consumption.

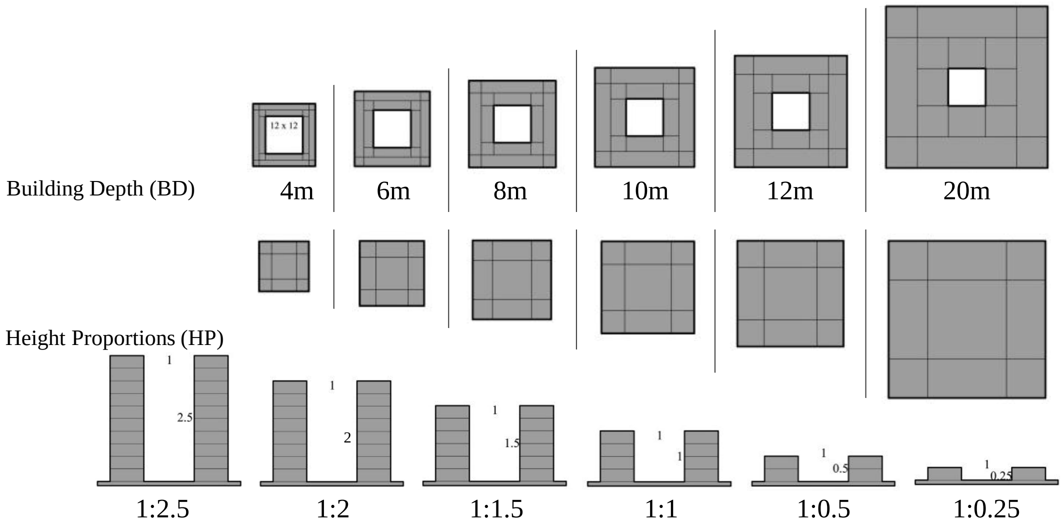

Figure 1: Tested courtyard height and building depth proportions and solid square buildings.

All courtyard and solid building cases were modelled using Design Builder software and simulated using EnergyPlus. Even at small building thickness, it was assumed the thickness is divided into two zones one facing the courtyard and the other on the external perimeter.

Table 1: Simulation parameters of tested Buildings

SIMULATION PARAMETERS				
BUILDING		**CONSTRUCTION**		
Form	Square	**External walls**	20cm concrete block + 2cm cement plaster each side	
Courtyard Dimensions	12X12m	**Internal walls**	10cm concrete block + 2cm cement plaster each side	
WWR	20% fixed for all forms	**Roof**	Insulated with 10 cm polystyrene foam	
Occupancy	0.13 person/m2	**Internal slab**	20cm concrete + 10cm flooring + 2cm plaster	
Schedule	Residential	**Windows**	Type	Double-glazed clear
HVAC		**LIGHTING**		
Cooling	23	**Type:**	Fluorescent	Suspended
Heating	21	**Daylighting control**	Illuminance: 300 lux	Dimming: On/off Sensor Height: 0.8m
Type	Split			

Simulations were performed for four cities: Alexandria, Cairo, and Khargah located in Egypt, and classified as hot arid according to koeppen-Geiger classification [12]. For comparison; Berlin, a temperate city with warm summer was simulated. Despite being classified as desert, the first three cities represent three different cases: Alexandria is a Mediterranean coastal city, Cairo is inland 220 km south of Alex., Khargah lies in the sahara 600km south of Alex. Figure 2 shows the difference in climate. Khargah is the highest in temperature, and out of comfort level for nearly all the year. Cairo is less in temperature than Khargah, yet higher than Alexandria. Berlin is the lowest.

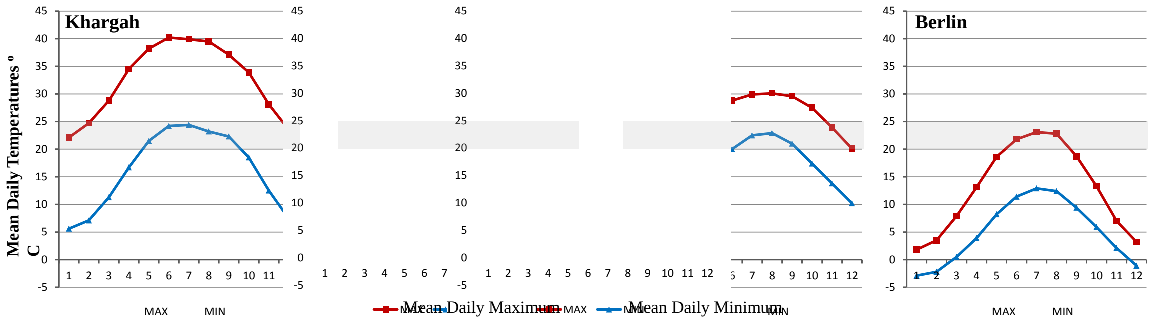

Figure 2: Mean daily maximum and minimum temperatures in tested cities for each month.

RESULTS AND DISCUSSION

Performance simulations showed a clear difference across the tested cities.

Height proportions:

In desert climates, results showed that EUI for all forms increased by increasing height in all cities. For example, In Khargah city, dominated by cooling loads, a courtyard building with BD 8m in different cases of floor HPs showed that the ground floor was always of the least consumption, then the second floor consumed more cooling energy, and starting from the third one the cooling energy at each floor were nearly constant, then it increased again at the top floor, Figure 3. This indicated that the ground floor was significantly lower in consumption due to the heat sink to the ground, while the top floor was higher but with a small difference than the preceding floor despite being subjected to the solar radiation due to the thermal insulation of the roof by 10cm. Thus in low-rise cases, the positive effect of heat sink on minimizing the overall EUI was significant. This effect became less as height increased.

As the tested buildings are fully air-conditioned with no natural ventilation, they were not directly affected by air temperature inside the courtyard. These results differed from what is expected in naturally ventilated courtyard buildings where height promotes natural convection, and stack ventilation. The decreased direct solar radiation at bottom floors increased lighting energy consumption, and its radiant fraction; and so, minimized the expected savings in cooling loads resulting from self-shading.

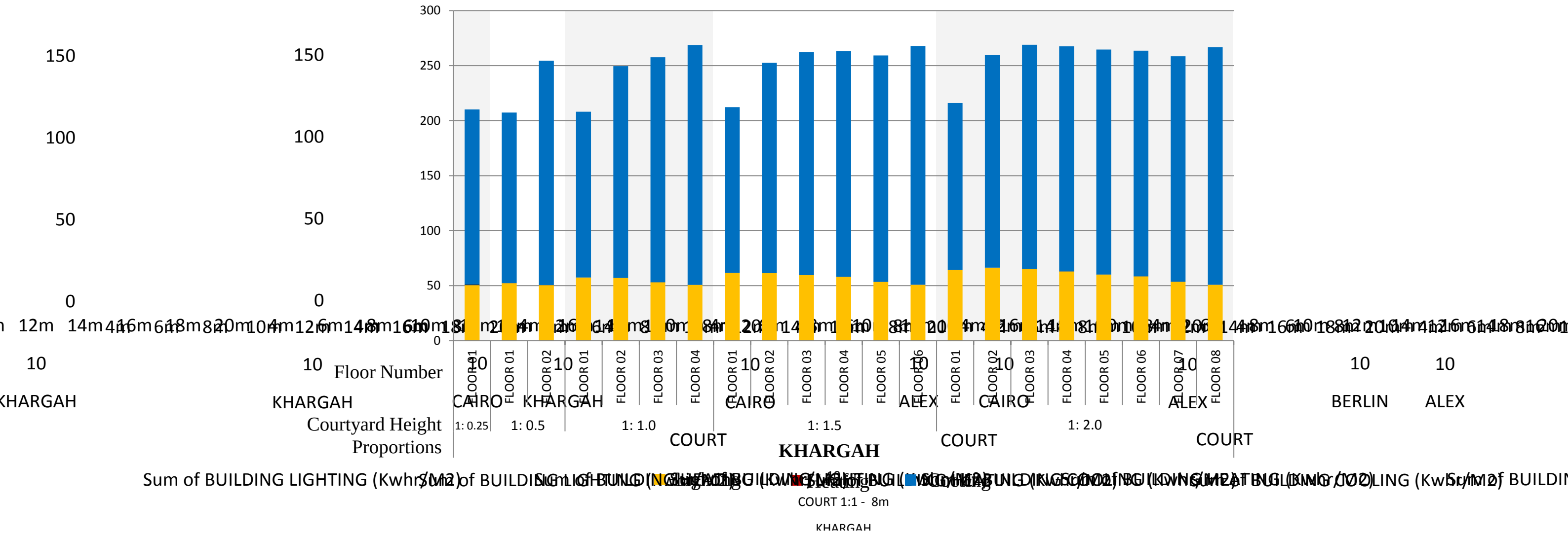

Figure 3: EUI per floor in courtyard buildings, with total height 1,2,4,6 and 8 Floors in Khargah city representing courtyard height ratios 1:0.25 to 1:2.

The reflectance of wall paint was assumed to be 50% as the color of the accumulated dust of the desert usually overrides the color of light paints.

In Berlin, dominated by heating loads, the contrary occurred. The heat sink lead the ground floor to consume more heating, making the building of 1 or 2 floors consume more than a the 4-storey one, then a gradual increase occurred as height increased, Figure 4.

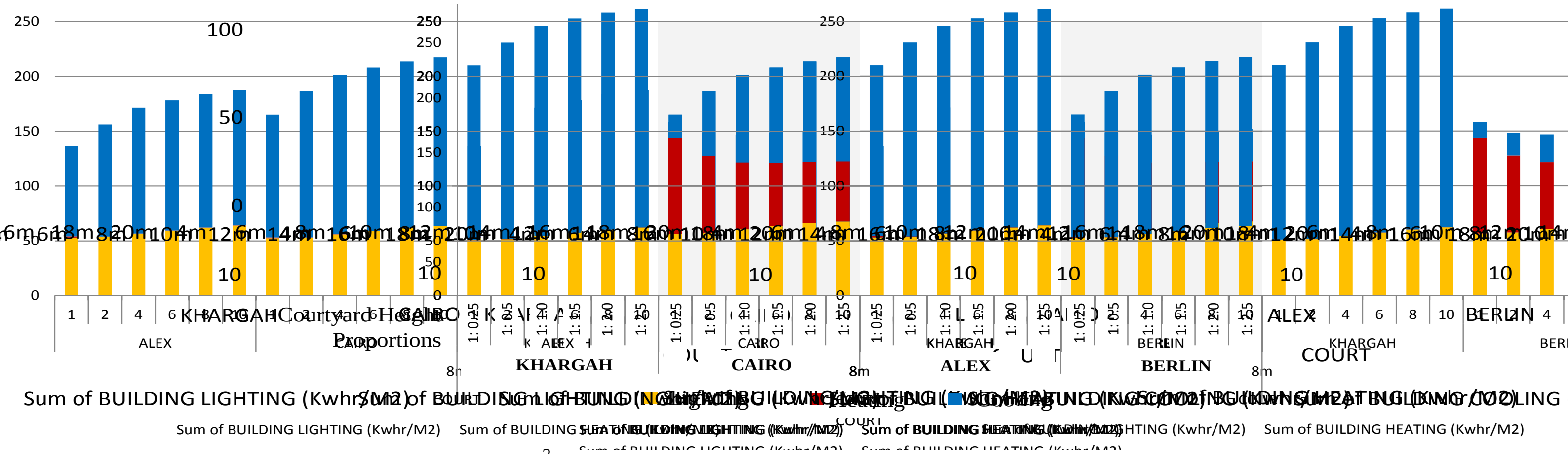

Figure 4: EUI in Kwhr/m^2 for courtyard building with BD 8m, in case of different building heights in the four cities.

In Cairo and Alexandria the same pattern occurred as in Khargah, however, consumption values differed according to climate. Figure 4 shows that increasing HPs lead to an increase in the overall energy consumption in all tested desert cities.

Depth of Building Surrounding the Courtyard:

Forms with BD alternatives 4m-20m surrounding the courtyard were tested. Changing BD while fixing courtyard dimensions means that the exposed surface area-to-built volume ratio (S:V) was also changed. This ratio was also changed by changing HP at each BD.

Results showed that in both extreme hot and cold climates of Khargah and Berlin, the BD was a determinant factor, Figures 5,6. In Khargah, as BD increased, total energy consumption decreased, in spite of the increase in lighting energy that was overcome by greater savings in cooling loads. On the other hand, in Berlin, the increase in BD lead to a large decrease in heating loads due to both the increased internal area protected from external conditions, as well as the increased lighting energy and its emitted thermal loads that help decrease heating loads, while increase cooling loads in summer. The result was a decrease in the overall consumption.

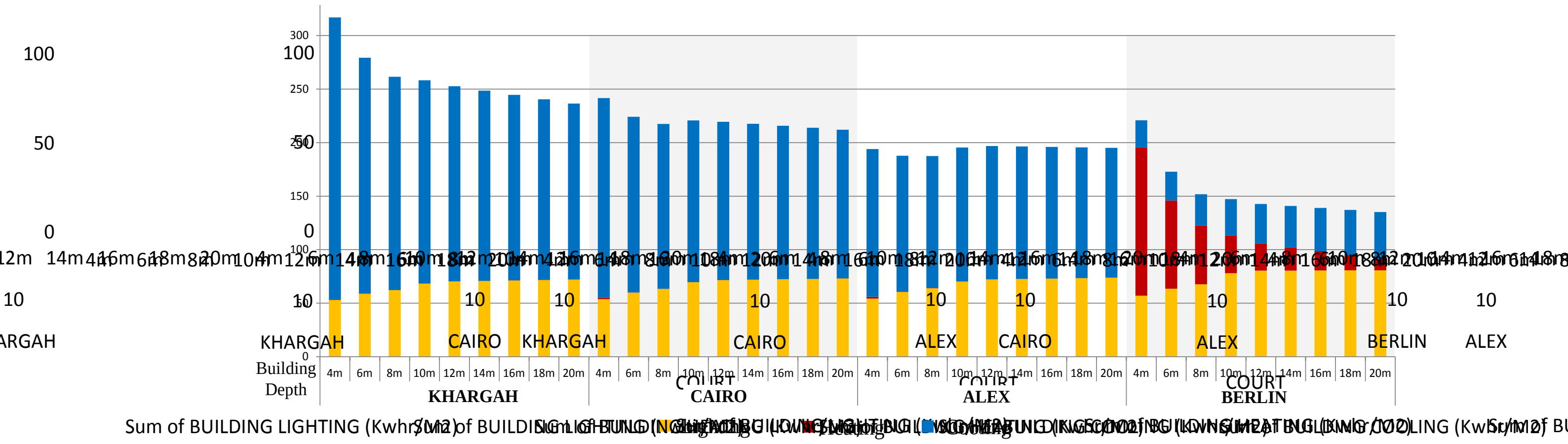

Figure 5: Energy use intensity in Kwhr/m2 for courtyard height proportion 1:2.5 (building height 10 floors), in case of different building depths in tested cities.

In all cities, BD 4m was of the highest EUI followed by BD 6m, as their S:V ratio were much higher than the other BDs, thus they were more liable to be affected by the outdoor climate. The S:V ratio for BDs 4 and 6m at HP 1:1 for example were 58%, 42% respectively, while BDs 8 to 20m ranged from 18-33% only.

In Alexandria, the climate is moderate and close to comfort levels for long annual periods. Cooling loads were not as high as the extreme environment of Khargah because the difference in temperature between indoor and outdoor is relatively small. For that, the effect of BD was the lowest of the four cities. Forms of different BDs other than 4m were of close EUI values. Lighting consumption increased uptill BD 8m then became nearly constant. Savings occured in lighting at low HPs, up to 1:1 (4 floors) and small BDs. The courtyard building with BD 8m was the lowest in consumption at all tested building heights. EUI of BD 6m was nearly similar to the rest of BDs starting from HP 1:0.5 (2 floors). The BD 4m case was of the highest consumption until HP 1:1.5 (6 floors), then became of similar values to BD 10-20m cases.

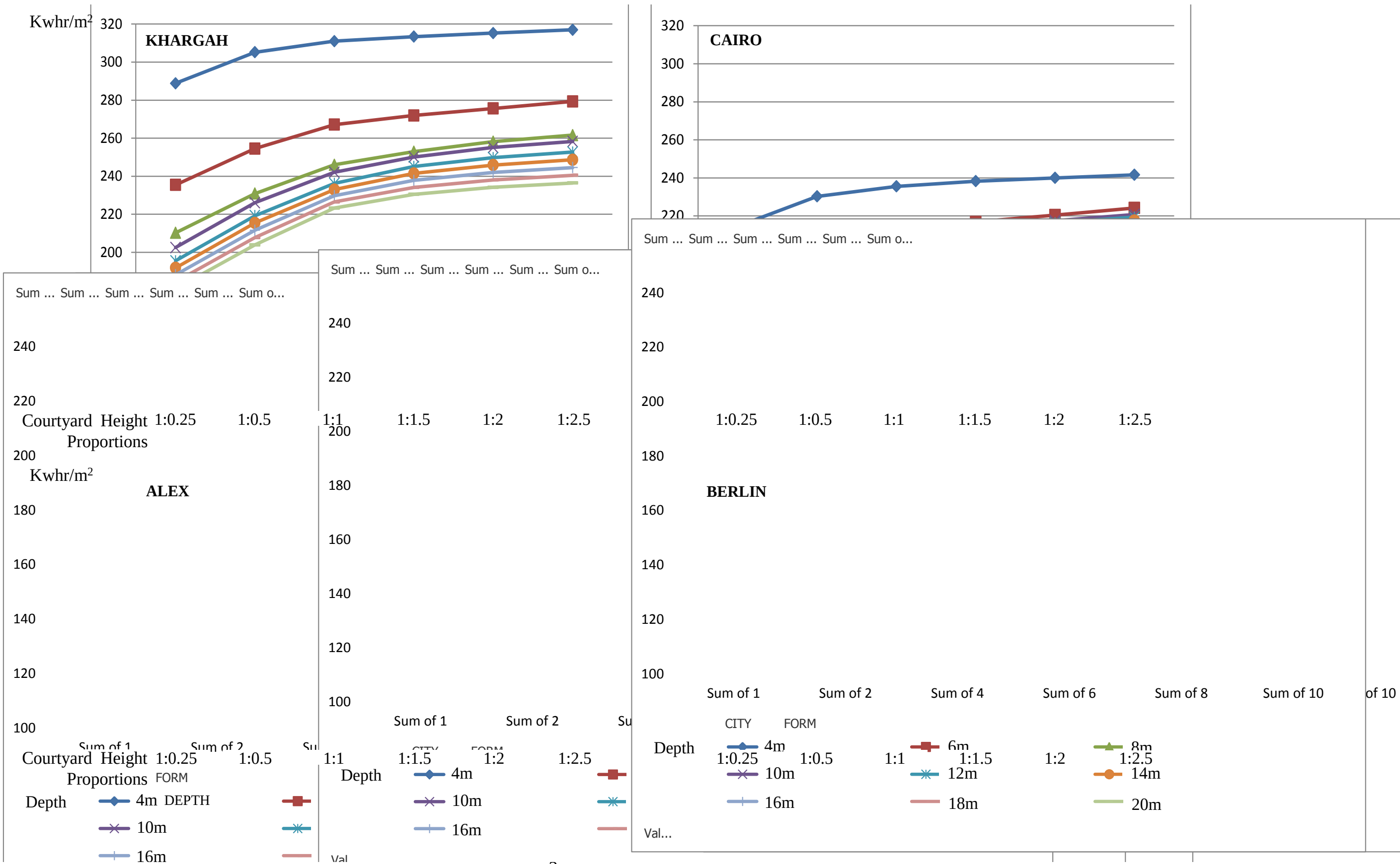

Figure 6: Energy use intensity in Kwhr/m^2 for courtyard buildings of different building depths and height proportions.

In Cairo, whose climate showed higher temperatures than Alexandria and lower than Kharga, results showed some similarity to either cities. As in Khargah, BD was inversely proportional to consumption, however, the differences in consumption between BD cases were much smaller than the corresponding values in Khargah, while larger than those in Alexandria. At BDs 10-20m, a slight decrease in cooling loads occured while lighting loads were nearly the same.

Courtyard or Solid Building:

In order to evaluate whether the performance of multi-storey courtyard buildings achieve savings in comparison with solid ones without courtyard, each of the tested building forms was compared to a solid square form with the same built area and no courtyard, Figure 7.

In Khargah, results showed that courtyard buildings did not achieve savings in any case of HPs for BD 4-14m, moreover, it lead to a significant increase in consumption. Only at BD 16m, minor savings occurred in case of HP 1:0.25 and 1:0.5 only. Also, minor savings were achieved in BD 18m at HPs upto 1:1. The only case where saving were achieved at all heights was in the BD 20m, especially at up to 1:1 height ratio, while up to 1:2, savings were very small.

In Berlin, courtyard buildings did not show any improvement compared to the solid square until BD 16m, at which saving were achieved in nearly all floors. Savings increased as BD increased. In most cases it caused a high increase in consumption that reached 40% in some cases.

In Cairo, minor savings were achieved at and some cases of BDs 8m and 16m. At BDs 18-20m, savings upto 6-8% were achieved at low HPs. The courtyard building consumed more energy than its corresponding solid building not exceeding 5% in most of the other cases except for BD 4m at low HPs.

In Alexandria, courtyard building achieved energy savings compared to their corresponding solid ones in the majority of cases. In the cases that did not achieve savings, the increase in consumption was was less than 4% except for BD 4m at low HPs. This indicated that Courtyard building is more liable to be used in the moderate climate of Alexandria than in other tested cities.

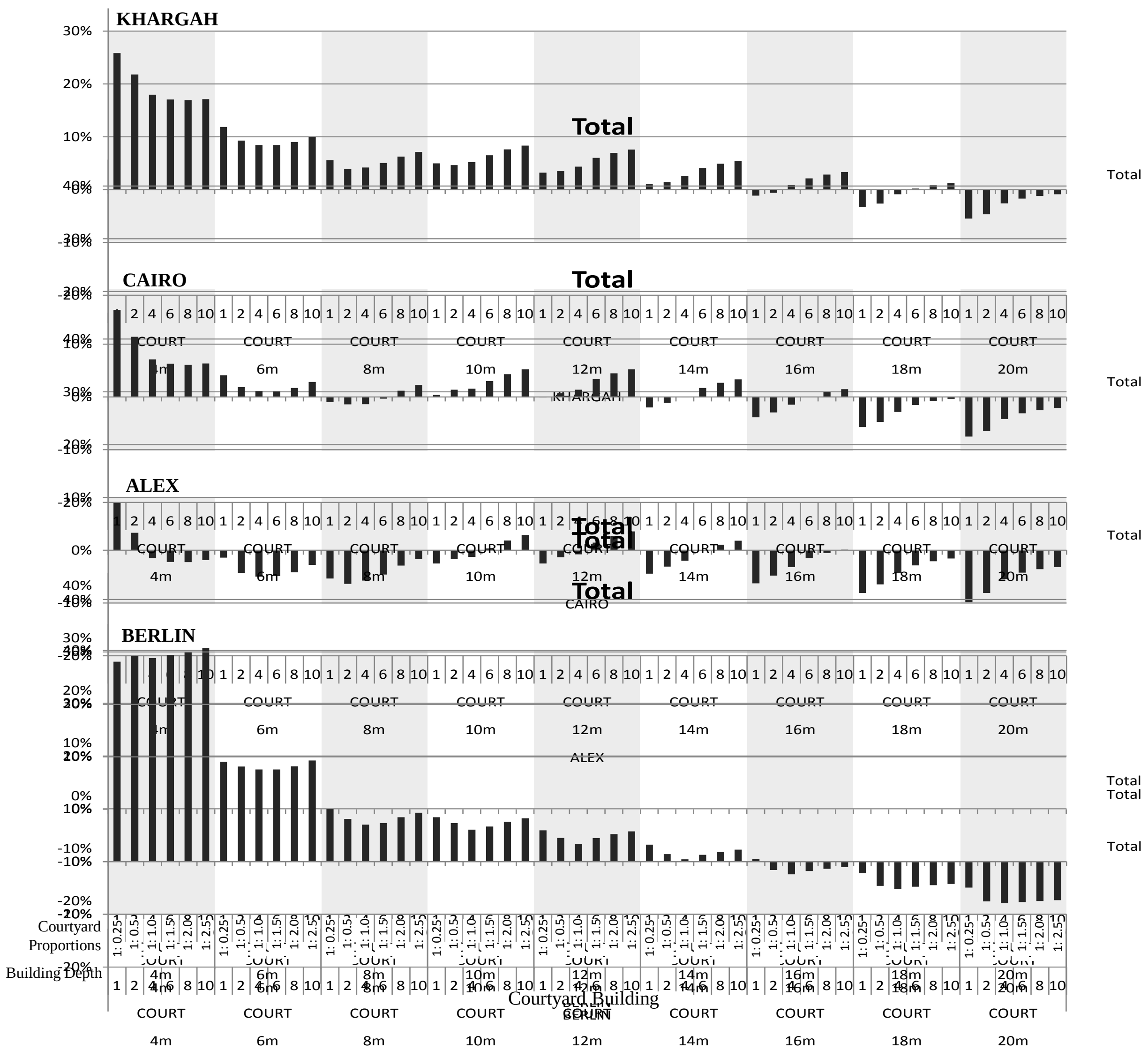

Figure 7: Percentage of change in energy consumption of courtyard buildings compared to its corresponding solid square.

CONCLUSION

Height proportions had a lower effect than building depth which was a key factor in the cities with extreme cold and hot climates, Khargah and Berlin. EUI values decreased significantly by the increase in depth due to the decrease of exposed surface area with respect to the indoor air-conditioned volume. This BD effect was less in Cairo and nearly insignificant in Alexandria where temperature differences between indoor and outdoor is small, thus decreasing heat transfer by conduction.

For a fixed depth, a courtyard with lower height proportions consumed less energy in desert cities due to the effect of the heat sink to the ground which became of less impact as height increased, leading to an increase in EUI accompanied by the increase in artificial lighting and its consequent cooling loads. This nearly cancelled the self-shading effect of the courtyard. The opposite effect occurred in Berlin.

Compared to the corresponding solid square, the courtyard building achieved significant savings in the moderate climate of Alexandria especially in case of medium height proportions (1:1) at small BD and in low height at large BD. In khargah and Cairo, that are more hot cities, significant saving were only achieved at large BD (18m-20m) and low height proportions (1:0.25 to 1:1) while a significant increase in consumption occured especially at small BD and higher height proportions in most cases.

Further research is required to quantify the effect of courtyard house with more proportions.

ACKNOWLEDGEMENTS

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Improving Ventilation Condition of Labour-intensive Garment Factories in Bangladesh

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ABSTRACT

The ready-made garment (RMG) sector of Bangladesh is based on the productions from the garment factories where workers are engaged in textile sewing activities, ironing and operating machines. Due to the generally poor quality working environment, these factory workers suffer discomfort and a range of health problems. It is widely known that the thermal environment of workspaces has a direct impact on physical comfort and hence productivity. In the context of a tropical climate, flushing-out the unwanted heat in these deep-planned production spaces is always a major challenge. Mechanical means that annually consume significant amount of energy are usually applied to resolve the ventilation issue. Potentially, passive ventilation strategies within the garment factory buildings may not only enrich the indoor working environment but also reduce carbon emissions. However, research has not yet demonstrated that passive ventilation strategies are viable in this sector. This paper describes an approach that may passively improve ventilation conditions in the existing garment factories of Bangladesh in terms of indoor air quality, thermal comfort; and, potentially, emergency smoke removal. These studies suggest that a methodology to develop passive ventilation strategies within existing garment factories is feasible in this tropical climatic context.

INTRODUCTION

RMG sector plays an essential role in the economy of Bangladesh, accounting for more than 80% of the total export earnings (Rahman et al, 2008) and nearly 10% of GDP (IFC, 2007). The production space (cutting, sewing and finishing sections) of this sector is usually human labour intensive. The workers' health, comfort and performance can be influenced by the quality of the production space (NAP, 2010). Hence, optimal working environment is necessary to maximise productivity (Prokaushali Sangsad Limited, 2007). Poor indoor environment has harmful impacts on workers' health (Wilson and Corlett, 2005) resulting in a high incidence of illness (Zohir and Paul-Majumder, 2008). The most frequent incidences are headache (98%), respiratory problem (36%), vomiting (28%), fatigue (28%) and fainting (18%) (Mridula et al., 2009). These are likely to result from the humid indoor conditions and lack of ventilation of the factories. After the 'Rana Plaza tragedy' in April 2013, new 'Alliance' and 'Accord' between RMG factories in Bangladesh and International organisations have been formed to ensure fire and structural safety in the buildings. However, improving the indoor workspace environments for workers' safety and comfort is also important. There is a significant amount of heat gain inside the building from the artificial luminaires, workers' body temperature and constantly in-use equipment (e.g. sewing machines, iron machines, etc.) (Hossain, 2011; Naz, 2008). The resultant gained heat is usually trapped at indoor due to lack of air changes. The factory owners use mechanical means to keep the indoor environment comfortable consuming a significant portion of energy. Local regulatory frameworks (e.g. 'Bangladesh National Building Code 2006') generally guide about

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window-floor areas for buildings which may not apply to the deep-planned one and need contextualisation (Ahmed, 2011). About 414 garment workers were killed in 213 factory fires between 2006 and 2009; and workers lost their lives in 2010 (Clean Clothes Campaign, 2012). During fire incidents, indoor trapped smoke is one of the main issues of fatalities (Akther et al., 2010) that correlated to ventilation efficiency.

In 2005, Ali showed that workspaces with light-wells of 'National Assembly Building' in Dhaka had optimum ventilation performance. Courtyards buildings also have advantages of increased incidence of natural ventilation (Ali, 2007). Increasing openings, soft surfaces and vegetation on facades were indicated as the possible solutions in Ahmed and Roy's study of 2007, while adding ventilation shafts in residential apartment buildings is a common practice. Even in a still outside air condition, required air flow rate can be achieved by changing opening size and location (Ahmed at el., 2006). Though cross ventilation is suggested in fully humid tropical context (Bay & Ong, 2006), these deep-planned buildings have no provisions of cross-ventilation. Hence, to get a passive solution in existing buildings, main possible solutions are to alter the fabric of the building, to add shaft or atria, to optimise space utilisation and to install control systems (Lush and Meikle, 1988). However, no research has been done prescribing any passive design solution for improving the existing RMG factory buildings in the tropical climatic context of Bangladesh.

OBJECTIVE

The main objective of the paper is to propose a feasible design approach that may passively improve ventilation conditions in the existing multi-storied RMG factories in context of Bangladesh in terms of indoor air quality, thermal comfort and potentially emergency smoke removal.

METHODOLOGY

Building selection method

As per recent database (May 2014) of the Bangladesh Garment Manufacturers and Exporters Association (BGMEA), a total of 5708 member garment factories are located in Dhaka region: Dhaka, Savar and Gazipur (74.7%), Narayanganj (17.9%) and Chittagong (10.8%). Approximately above 80% of the factory buildings, listed under the recently developed alliance and accord, are multi-storied. Hence, considering the existing building stock scenario, it was justified to choose a multi-storied RMG building within Dhaka region to establish a tangible and replicable outcome. In reference to previous studies (Naz, 2008; Hossain, 2011 and Fatemi, 2012), the major archetype of multi-storied RMG buildings was of 'shoe-box' shape (either rectangular-oblong or tapered). Hence, after getting shortlisted buildings according to selection criteria, a typical shoe-box shape building within Dhaka region has been selected for the pilot study.

Empirical data and physical viability testing method

In the site-micro climate analysis, the local meteorological data and updated weather file of Dhaka region along with computer aided tools (i.e. 'Autodesk weather tool, 2011' and 'Climate consultant 4') have been utilised. 'Ecotect Analysis 2011', an established validated tool in previous academic M.Arch and PhD research, has been used for the shadow and solar radiation study only. As a part of Hossain's research in 2011, a HOBO scientific 'data logger' with Dry Bulb Temperature (DBT), Relative Humidity (RH) and Air Velocity sensors (placed in the centre of the 1st floor at 2.1 m height level) was moderately used. Other Information (i.e. numbers of workers, activity types, equipment etc.) have been collected during Hossain's previous field study in 2011. A calculation tool 'Opti-VENT' (developed by Brian Ford & Associates), with contextualising the input data (e.g. deploying the solar radiation data from the Ecotect analysis, design DBT target from Fatemi's study, 2012), was accomplished to test the physical viability. 'Bentley Tas Simulator V8i' has been applied to validate the logged-data and evident the thermal improvement of the workspace.

Questionnaire survey and practical viability testing method

An online questionnaire survey was conducted to get feedback from the owners and directors of RMG (18 respondents) factories in Bangladesh. The 11 structured questions were formulated to understand their perception on natural ventilation and energy cost, refurbishments and to identify possible constraints.

PROPOSING A PASSIVE VENTILATION APPROACH

Site and Micro-climate Analysis

The impact of local climate: Plotting the local climatic data reveals that the local DBT varies between 6~37°C within different periods of the year. Hence, the local seasons can be classified into major three categories (figure 1a): warm-dry (DBT 28.08°C), warm-humid: monsoon and post-monsoon (28.08°C and 26.6°C) and cool-dry (19.9°C). During the occupied period of the factories, both outside DBT and solar radiation are relatively high (figure 2b) which can be utilised or controlled for passive ventilation.

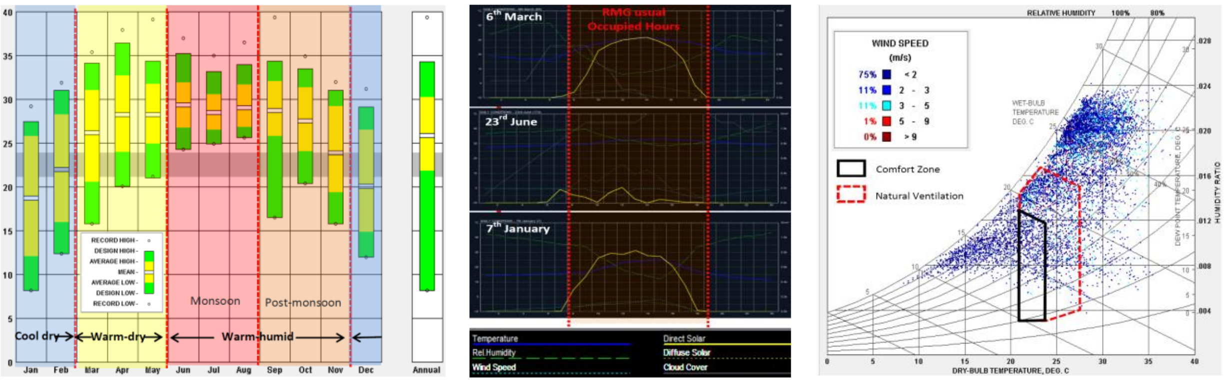

Figure 1: a) Seasonal variation of DBT b) Daily DBT profile c) Psychometric charts showing boundary of natural ventilation (Source: Climate Consultant 4 and Autodesk weather tool 2011)

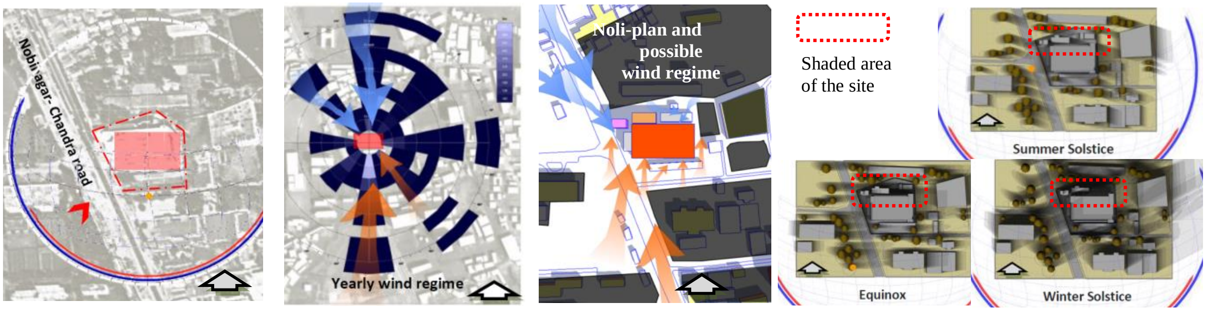

Figure 2: Location of the building, local wind regime with future development and shadow pattern analysis (source: Google map, Ecotect analysis 2011 and Autodesk weather tool 2011)

Phychrometric chart analysis: According to ASHRAE comfort range, comfort can be achieved in at least 9.3% period of the year utilising the natural wind speed (figure 1c). It can be extended by reducing RH or increasing air flow. However, in 2012, Fatemi proposed the garment workers' higher comfort range of 28.5-33°C BDT and 56-72% RH if the air velocity is 0.8-1.5 ms-1. Hence, passive ventilation in the studied building may still deliver comfortable air temperature for the workers covering more period of the year.

Physical context and wind regime: Heavy traffic road at west side (Figure 2) is a source of polluted air and noise. Wind with higher velocity usually approaches from the south, south-east and north side towards the building site during the warm-dry and cool-dry periods. However, considering the future development, wind of reduced velocity may be able to reach to south and north building-facades where major operable openings are also located. Considering sun-path and shadow analysis (Figure 2), the north facade's wind regime, usually shaded, can be the source of cooler air during daytime working hours (Ford, 2010). Figure 3 also illustrates that the north façade and the ground level area adjacent to a five storied building can potentially deliver cooler air. In contrast, the south façade and roof have higher solar radiations. Hence, these facades require solar control (Akbari, 2007) to avoid external heat gain (e.g. 1000~1800Wh solar radiations).

Effect of Street pattern, Vegetation and Urban Heat Island (UHI): The existing street pattern and vegetation reveals that west-side air must be avoided, while south and south-east vegetation is the source of fresh air. Since the site is 26km far from Dhaka city, local temperature can be less affected by UHI effect.

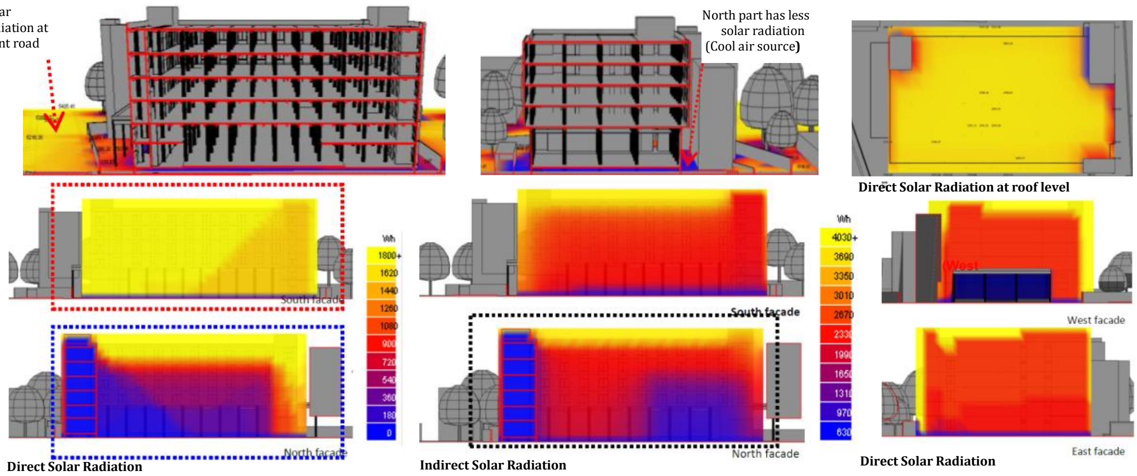

Figure 3: Solar radiations in the hottest day of a year (source: Ecotect Analysis 2011)

Based on the finding in the microclimate analysis and literature review on ventilation principles (table 1), it can be proposed that free running 'natural ventilation' can be applicable in cool dry and partially hot-dry seasons (40% of the year), while night ventilation and evaporative cooling is also partially applicable in these seasons. Other seasons may need dehumidification due to high level of RH.

Table 1: Summary proposal from the findings of micro climate analysis

Climatic seasons	Months	Potential natural ventilation approaches (options)	Ventilation principal	Exploitation of fresh air and wind regime	Required Solar Control
Hot-dry	Mar-May	Natural ventilation Night ventilation (Thermal mass)	Wind forces Thermal forces	Wind from the south	West and South façade
Warm-humid: Monsoon	Jun-Sep	Dehumidified cooling	Thermal forces	Wind from any direction (except the west side)	West façade and South facades
Warm-humid: Post monsoon	Oct-Nov	Dehumidified cooling	Thermal forces	Wind from any direction (except the west side)	West and South facades
Cool dry	Dec-Feb	Natural ventilation (with control) Evaporative cooling (Limited)	Wind forces Thermal forces	Wind from the north (with control strategy)	West and South facades

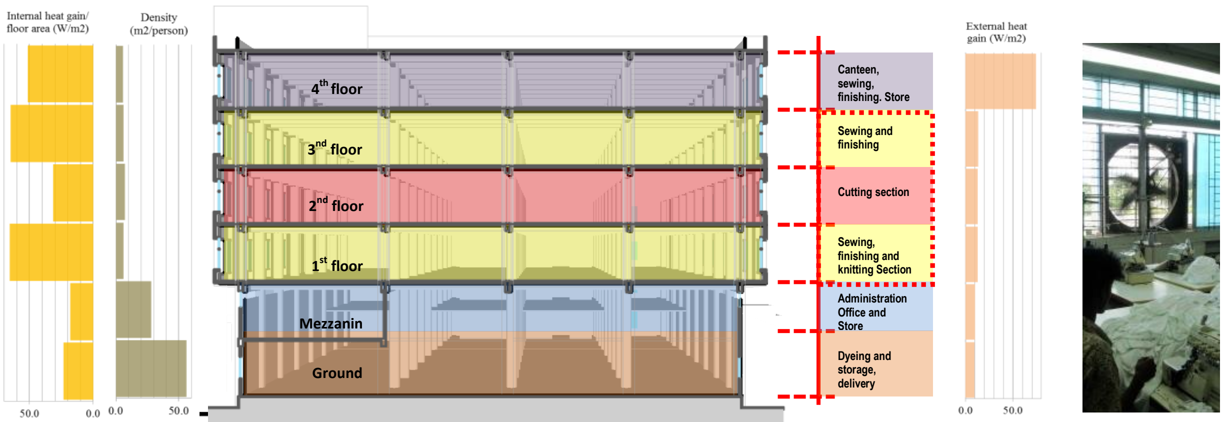

Figure 4: Functions, heat gains and occupancy density of studied building (source: field survey 2009)

Building baseline condition and environmental aspect analysis

Considering the work-type, workers' number, equipment and above all the artificial lighting configuration, it reveals that 1^{st} and 3^{rd} floors have higher heat gain and 1^{st} ~4^{th} floors have high density (figure 4). Moreover, the top floor has higher conductive external gain from roof. To resolve the ventilation issue, ceiling fans and extractors are partially added. The logged-data (figure 5a) clearly reveals that even after having mechanical ventilation, the internal DBT is high during occupied period. Moreover, plotting the field measured DBT in compare to local meteorological data (figure 5b); it can be observed that the heat was trapped inside the production space with a maximum 11degC of indoor-outdoor temperature difference (ΔT).

The trapped heat also implies that there was not enough air change rate available in the workspace during the cool-dry season (namely the month of December). An empirical data of Naz (2008) showed that sewing and ironing section could have high DBT of 35°C-39°C with minimum ΔT of 3-5 degC in warm-humid season.

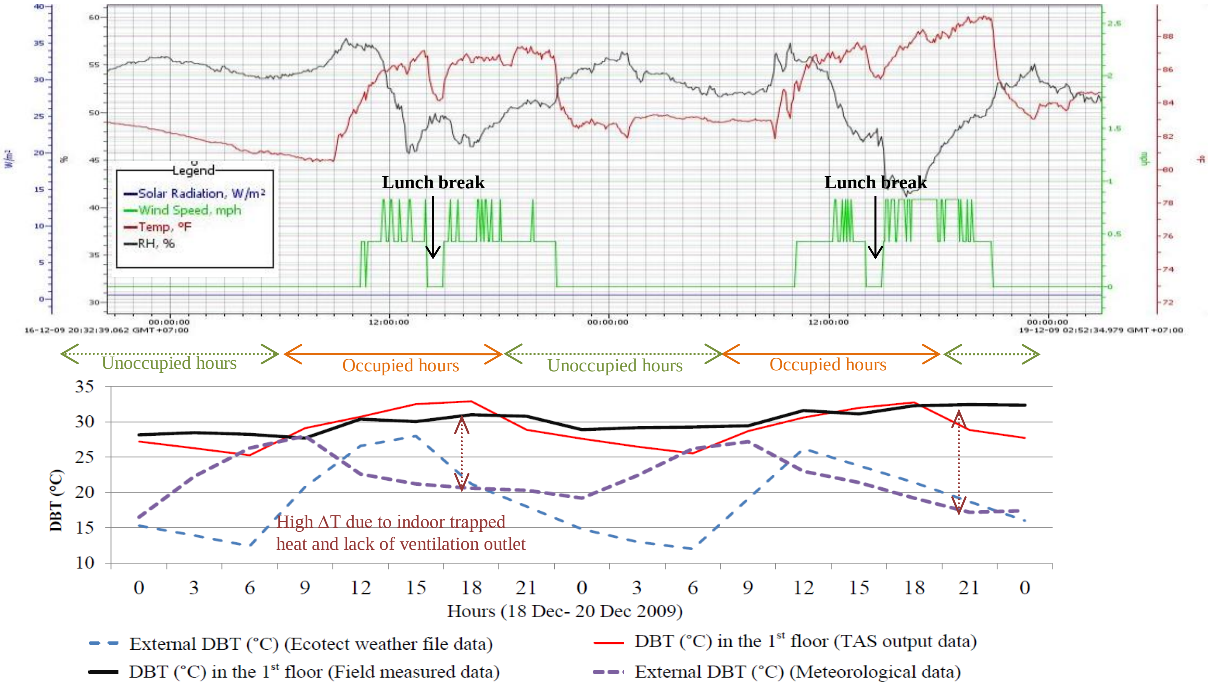

Figure 5: a) field logged data of the 1st floor and b) comparative diagram of DBT in 1st floor (Source: Hossain 2011, previous field survey, weather tool generated data and TAS output data)

To sum up, the micro climate analysis and existing empirical evidence shows that thermal principles (considering ΔT and cooler air sources) may be utilised and ‘stack induced ventilation’ can be proposed as a robust solution in this pilot surveyed building.

TESTING THE PHYSICAL VIABILITY OF THE PROPOSED APPROACH

For effective stack ventilation, three concerned variables are: effective area of the inlets and outlets (A), ΔT and stack height (H), where indoor air flow rate is directly proportional to these variables. Estimated air flow rates can be compared with target design flow rates required for fresh air and comfort cooling; while required air changes are 1~2 ACH and 12~15 ACH respectively (Baker, 2013). For more flow rate, the outlet size and/or the stack height need to be higher. For calculating solar gain, roof surface absorbance, roof U-Value, roof external surface conductance are assumed as 0.65, 1.15 W/m^{2}K and 8.5 W/m^{2}K respectively.

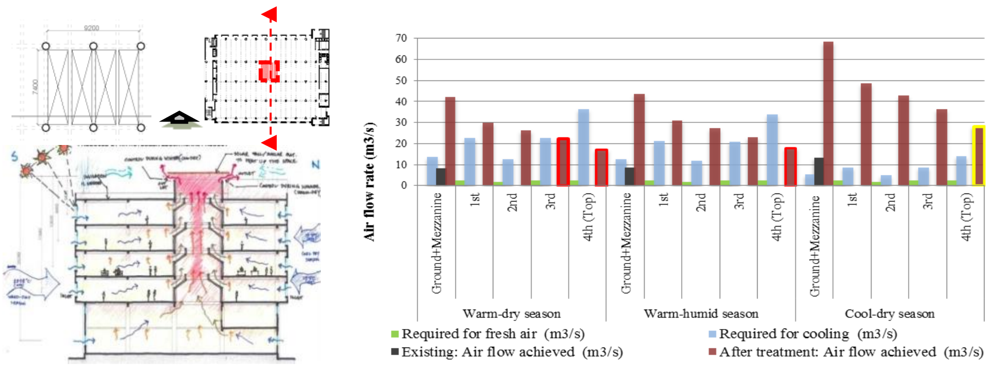

Figure 6: a) Preliminary design and b) Comparative air flow rates (source: calculation by Opti-vent)

Testing by a preliminary shaft design: The outlet sizes can be determined from the ‘required air flow rates’. However, to keep it simple in preliminary design, initial ventilation shaft’s size was determined following the existing beam-column layout (Lomas, 2007). In the preliminary design step, a modular size of

9.2mx7.4m (3.78% of each floor area and *7.4mx2m* each of four modules) has been selected and located centrally within the building (figure 6a) believing it may help to equally remove the warm air from all surrounding indoor area. Thus the maximum allowable area of the shaft in each floor is $9.2X7.4=68.08m^2$ and maximum perimeter is *2X9.2+2X7.4=33.2m*. The *inlet sizes* are determined from the existing opening (35% effective). Considering average outdoor BDT in three seasons (figure 1); three cases were preliminarily considered where assumed ΔT were 5.2, 5.6 and 13.4 degC. An initial shaft height was also assumed (figure 6a) with a stack height of maximum *25.3m* in the ground floor and minimum *6m* in the top floor. Figure 6b shows that the proposed shaft has met the fresh air flow targets in all seasonal cases. However, the 3rd and 4th floors have not met the cooling targets in warm-dry season so as the 4th floor in the warm-humid case. In cool-dry case, it has been gained in all floors. Increasing stack height may improve the condition.

Table 2: Estimation of structural and effective outlets size to test physical viability

Floor	Structural inlet (existing window in N+S sides) m^2	**Case 1:** Hot seasons while average ΔT=5 degC (represents warm-dry and warm-humid seasons)				**Case 2:** Cool seasons while average ΔT=11 degC (represents cool-dry season)				Required max. shaft perimeter (outlet-height is 1.2 m) m
		Required structural outlet for cooling, m^2	Effective outlet (50% structural)	Effective outlet at shaft-top (50% structural) m^2	structural outlet at shaft top m^2	Required outlet for cooling m^2	Effective outlet (50% structural) m^2	Effective outlet at shaft top (50% structural) m^2	structural outlet at shaft top m^2	
4th	97	152.4*	76.20*	125.6*	251.2*	19.6	9.8	23.6	47.2	127.0*
3rd	97	37.7	18.85			10.2	5.1			31.4
2nd	97	17.2	8.60			5.1	2.55			14.3
1st	97	29.2	14.60			8.2	4.1			24.3
Gr+Mez	49	14.7**	7.35			4.1	2.05			15.35**

**In 4th floor, the required effective outlet area and shaft perimeter are not feasible to achieve due to high shaft perimeter requirement.*

***In Ground-Mezzanine floor, the outlet would be a horizontal opening in the ceiling (figure 7). Hence, perimeter has been calculated directly from required structural area (14.7m) assuming area $14.7m^2$ =4mx3.68m and perimeter 15.35m=2x4m+2x3.68m. Hence, 1.2m height of outlet is not applicable here.*

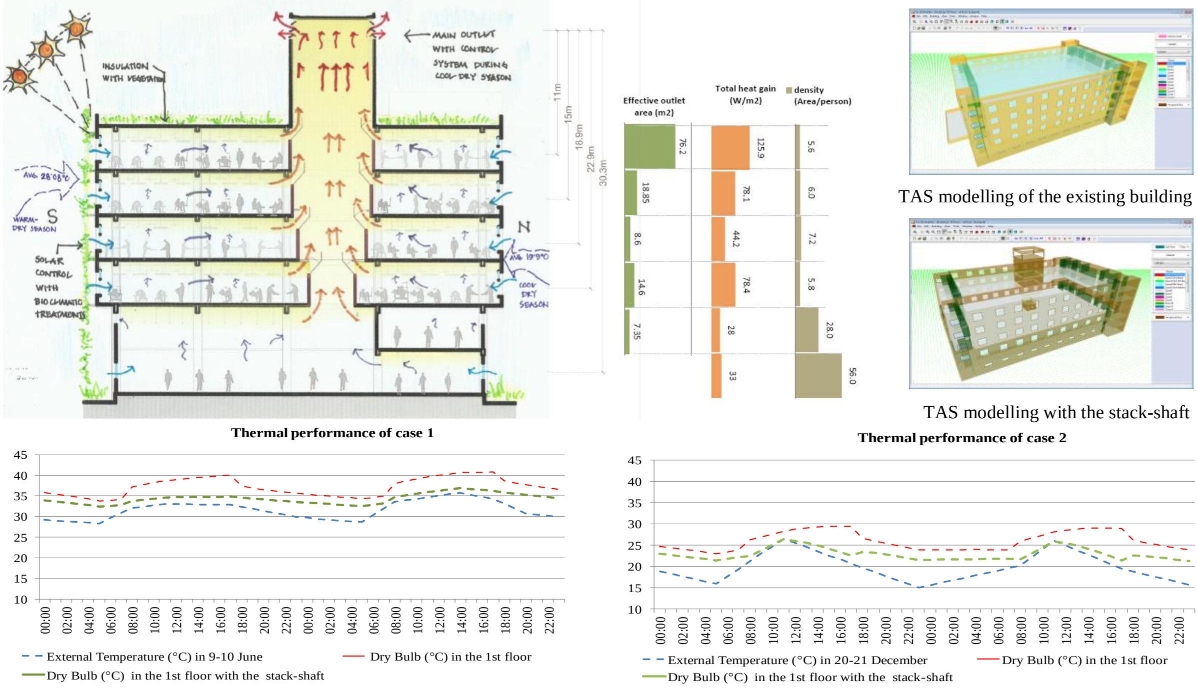

Figure 7: a) Proposed passive ventilation approach to improve ventilation condition b) Improvement of Thermal performance with proposed shaft (source: TAS simulation)

Testing by effective area (A) of outlet: An increased stack height has been assumed where maximum stack height is *30.3m* in the ground-mezzanine level and minimum *11m* in the top floor. The effective *outlets* of the shaft (50% of the structural openings in each floor and at the top of the shaft) were actually the free areas to drain warm and stale air. Required cooling flow during warm seasonal conditions always determines the effective free area of opening required (Lomas, 2007). Hence, at this stage, only two cases have been considered, where case 1 and case 2 represent the hotter (ΔT = 5 degC) and cooler (ΔT = 11 degC) seasons respectively. As the area for the outlet available in the perimeter, rather than the cross sectional area of the shaft, determines its effective area (Thomas, 2007); for variability the maximum effective outlets need to meet two criteria: to achieve cooling flow target in case-1 ($38.14\sim13.39m^3/s$) and *perimeter* of the shaft would not exceed 33.2m per floor. From Table 2, it can be noted that the outlet size of the 4^{th} floor does not meet the criteria. The primary reasons behind this situation are excessive heat gain (12.9 W/m^2), worker-density (5.6 m^2/person) and lower stack height (11m). Apart from the top floor in case-1, the calculations clearly demonstrate that the sizes of the effective outlets are easily achievable to incorporate in the existing building with minimum shaft perimeters between *15.35m* and *31.4m* (as shown in table 2 and figure 7b).

Thermal analysis with 'TAS' simulator: Figure 6b reveals that 'TAS dynamic thermal modelling' output data has acceptable deviations (maximum 2°C) with the logged-data, which also establishes its validity. Incorporating the effective outlet shafts and achieved air change rate in the pilot studied building (figure 7a), it is revealed that this passive design approach can reduce 2~5°C and 2~7°C DBT (figure 7b) in Cases 1 and 2 (table 2) respectively in the studied first floor.

Considering all analyses, it is evident that it is physically feasible to design a central supply route as a shaft of sufficient cross-sectional area to achieve a presumed design air flow rate and reduce indoor temperature as an improvement of the indoor workspace environment within this existing studied building.

VIABILITY OF IMPLEMENTING THE PROPOSED STRATEGY

From the questionnaire survey, it has been found that the majority of the factories consume 1000-2000KWh (33%) and above 2000KWh (61%) of electrical energy with an annual average expenditure of US$2500-6250 (39%) and above US$6250 (56%). All the factories are using mechanical ventilation system, though they know it consumes significant amount of electricity. 50% of the stakeholders claimed that they have emergency smoke removal system. The other results (figure 8) reveal that about 72% of stakeholders are inclined to adopt a passive ventilation strategy and 78% would like to undertake refurbishments to improve ventilation condition. 72% may invest US$6250-12500 to implement the strategy subject to an assured return on investment within 5 years. Survey result deployed that the possible challenging issues of execution are construction, disruption of production, existing functional layout and reduction of floor area.

Figure 8: Stakeholders' feedback on adopting passive ventilation strategies and any refurbishment

CONCLUDING REMARKS

Stack driven ventilation and night cooling can be utilised to improve the air flow rate in all seasons, with a free running period of about 40% of the year, in the studied building in Bangladesh and to save a significant energy cost. A common shaft can be incorporated at every floor to naturally remove the trapped hot air from the production floors. Effective outlet for cooling may always meet the target of air quality. However, improved thermal condition at the top floor is difficult to achieve in warm seasons due to conductive heat gains of roof. Relocating functional zones with less internal gains towards top floor within a building may potentially optimise ventilation performance and shaft-outlet size. Moreover, the inlets may need dehumidified cooling and bio-climatic solar control to ensure cool air inflow in warm seasons. Preliminary shaft size should be determined from the modular structural layout and strength, equipment and work-lane dimension, etc. for efficient space usage. Based on relationship between ΔT and air flow rate, during any fire hazard, the temperature of that floor automatically increases which eventually increase air volume flow speed of the stack ventilation due to the raised ΔT. Furthermore, the hot air containing smoke will naturally travel through the shaft subject to effective air back flow control. This may reduce indoor trapped smoke and workers may, therefore, get an additional time to evacuate from the fire incident floor.

RMG factory owners and directors are affirmative about adopting passive strategies and refurbishments to improve ventilation condition. Hence, methodology of implementing proposed passive strategy may be practically viable subject to it is within owners' budget and payback plan (i.e. cost-benefit analysis) through energy saving and increased productivity with minimum disruption during execution of the refurbishment.

An extended field investigation can be developed to observe workers' adaptive comfort strategy. Emerging passive design cases and associate cost estimations can be part of the extended research with some extended questionnaire survey and interviews. This paper has attempted to demonstrate a feasible passive design approach to improve the ventilation condition in existing RMG factories. The authors look forward to pursuing further extended research with more field evidences, sophisticated analyses and larger samples.

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The Impact of Tropical Classroom Facade Design Alternatives on Daylight Levels and Cooling Energy Consumption

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ABSTRACT

In educational buildings the use of daylight may not only improve students' learning performance but can also reduce electric lighting energy consumption. However, in tropical climates allowing daylight in to rooms can also create a potential overheating risk and increased cooling energy requirements in order to achieve thermal comfort. In this study an actual educational building located in Thailand was investigated using the DesignBuilder modelling package. Daylight levels in several classrooms were measured in order to check the validity of DesignBuilder predictions. A series of classroom façade design alternatives were then investigated by modelling them and analyzing their influence on visual and thermal comfort and cooling energy requirements in each classroom. The aim of the study was to suggest optimized design solutions that created good daylight levels in classrooms but without excessive cooling energy requirements. Some of the different facade designs were found to perform adequately in terms of light levels but poorly in terms of cooling energy usage. Parametric studies such as this one can inform the solution concept and facilitate decision making for designers at the preliminary stages of a design. This paper suggests some facade solutions that could be applied generally to classroom design in tropical regions to achieve a good compromise between daylight access and thermal comfort.

INTRODUCTION

Many studies, such as Altomonte (2009), have confirmed the positive effect of natural light on human visual quality and psychological well-being. There is some evidence, for example Halliday (2008) and Lee et al. (2012), of the advantage of daylight to student learning performance. Results from Theodorson (2009) appear to support this idea by suggesting that good views of the outside world are associated with an improvement in student performance. Although the National Research Council (2006) pointed out that the evidence was too limited, it concluded that a classroom without a window can create stress in students. Windows in façades which directly provide daylighting are, therefore, necessary and desirable in classrooms.

Research background

The provision of natural light to rooms in hot-humid climates leads to two major issues - thermal discomfort and visual quality. Correct façade design is one of the significant solutions to optimizing daylight use in buildings. This research aims to investigate the influential parameters of façade design and to recommend some design guidelines. In this paper the influence of window area and overhang depth on classroom illuminance levels, thermal comfort and cooling energy consumption were examined.

Literature review and research questions

For both human and visual comfort, several façade design strategies have been investigated by researchers – for example, Aksamija (2013). There strategies include glazing type, window size, window orientation and window shading. In terms of thermal performance, Perez and Capeluto (2009) stated that glazing type, window size and orientation have very high impacts while window shading has a high impact on energy consumption. Zurigat et al. (2003) also presented some relevant results. Compared to other strategies, shading devices seem to have low impact on cooling load. However, cooling load could be reduced by up to 11% when shading devices were applied. Window shade consequently was recommened to be an additonal strategy to lessen cooling load. Concerning other factors, Catalina and Iordache (2012) argued that window size does not have a major influence on operative temperature. In daylighting research some studies were found to be useful for facilitating design decisions but, generally, most studies focused on one specific daylighting aspect. There is a lack of literature that attempts to integrate façade parameters, daylighting and thermal issues. When considered separately, it is obvious that for glazing type and window size then the higher the light transmittance and the larger the window area then the higher the prevailing daylight levels. Similarly, less window shading helps more natural light into the room. However, those strategies are probably not proper solutions. Their expected negative outcomes may consist of excessively high light levels and direct sunlight can bring about visual discomfort or disability glare. Because of glare and disturbrance the USA's National Research Council (2006) pointed out that natural light can cause negative effects on student performance, particularly when direct sunlight enters the classroom. Boubekri and Boyer (1992) partly disagreed by claiming that unless directly facing a window, occupants were rarely influenced by direct sun or glare. The significance of shading devices for daylighting which was affirmed by Dubois (2001), who implied that just changing occupants' position and vision may not be the right solution. The optimization of those façade design parameters for improving and controlling light levels is still an important question. A southwest facing façade, as one of the orientaions which is largely dominated by low sun altitudes, was chosen in this study for assessing the impact of window size and shading. Overhangs were initialy studied not only because of their simplicity but also because overhang investigations by Dubois (2001) suggested that they were probably suitable for horizontal visual tasks as they provided sufficient illuminance. At this stage other influential factors, such as glazing type, and other potential components, such as light shelves, were not included in this study. In addition, lighting control systems may, as suggested by Perez and Capeluto (2009), have a high impact but are required to be combined with other façade parameters.

Research methodology

As an example of typical classrooms in Thailand, some classrooms in the Faculty of Architecture, Mahasarakham University were investigated using the DesignBuilder software. Twelve façade variations of window areas and overhang were applied to the representative classroom model, which was oriented to the southwest. Window area parameters consisted of (i) no window, (ii) existing window and (iii) glazed wall with percentages of glazing varying as: 0%, 31.5% and 100% (fully glazed wall). The parameters of overhang depth were (i) no overhang, (ii) existing overhang with a 2.1 metre depth, (iii) existing overhang with 4 metre depth and (iv) 7 metre depth overhang with percentage depth varied as: 0%, 30%, 57% and 100% (7 m depth), repectively. In addition, the two opposite fully glazed cases were included in order to examine the influence of the façade in the opposite sides of the room. The study focused on predictions of total cooling load (kW), Fanger PMV comfort scores, average maximum illuminance and daylighting distribution. These parameters were simulated hourly during the building's working hours for weekdays. Two other indicators were considered: the illuminance ratio (highest to lowest illuminance ratio in room) and the percentage of classroom positions where illuminance levels met a stated standard. Cantin and Dubois (2011) recommended the Useful Daylight Illuminance (UDI) as a practical indicator. The UK's Department for Education and Employment (1999) recommended classroom light levels of 300-500 lux, and an upper threshold of UDI of 2,000 lux was chosen. CIBSE (1994) recommended 1:10 as an illuminance ratio between the task and more remote lighter surfaces, but Cantin and Dubois (2011) pointed out that this appears too strict. They suggested instead the ratios of 1:20 and 1:50 as acceptable and tolerance ratios. In this paper these three ratios will be applied as recommened, acceptable and tolerable limits. Apart from simulation modelling, the case study school was also surveyed. The daylight level measurements and occupants' satisfaction survey were completed for validating the prediction and studying actual problems.

PROBLEM MORNITORING OF THE CASE STUDY

Supansomboon and Sharples (2013) reported results of the survey, which was done during June 2011. The satisfaction survey and the measurement are concordant in terms of insufficient illuminace levels. The participants raised a variety of problems regarding variations in light levels which can decrease their effectiveness in all visual tasks. The measurements also showed that the differences in maximum and minimum illuminance and luminance values were considerably higher than design recommendations. One of the crucial causes was the influence of direct sunlight enerting the room. In addition, it was also found that, although the majority of classroom users agreed with the advantage of applying natural light, their actual behavior appeared to rarely use daylight. This was due to the fact that the natural light is generally fluctuating and the existing shading devices are not only inadequate for preventing direct sunlight but also difficult to operate. These results reveal that the exsiting classroom façade might not be suitable for daylighting. Adjustment of the façade appears to be necessary to solve fluctuation of the daylight and optimise the different visual task requirements.

DAYLIGHT LEVELS

Daylight level distributions for sidelighting generally display a common pattern. The illuminance is maximum in the area next to the window and then reduces dramatically with distance from the window into the rear area. For the case study, when illumination levels were collected during the period of summer solstice, on average, this pattern was observed. However, the average illuminances did not meet the recommended standard of 300-500 lux for all measured positions. When measurement positions were considered separately, the daylight levels of the mid position and the furthest position had no significant change during working hours - the average illuminances were approximately 150 and 50 lux respectively. Conversely, illuminance levels in the position next to the window did vary with time. Illuminance levels were, on average, about 250 lux in the morning and increased to a peak value of about 350 lux at 2.00 pm and then reduced until the end of working hours. The minimum illuminance was about 120 lux. The results suggest that the daylight levels are insufficient at all working times.

Validation of illuminance predictions

The sky was classified to be partly couldy sky but the percentage of cloud in the sky varied. When the measurements and predictions were compared, it was found that none of sky conditions provided in the DesignBuilder lighting module had exactly the same pattern as occurred during the measurements. However, two sky conditions were accepted that could represent minimum and maximum illuminances. In term of patterm similarity, the sunny clear sky condition is the condition that matches the peak illuminance at approximately at 2.00 pm. The illuminances at the mid and the furthest positions from the window were, on average, close to the measurement values. The lowest illuminances were predicted for the overcast sky. At the position next to the window, the value was near the average illuminance of the measurements.

Influence of time and season

The predictions for the exiting façade model under a sunny clear sky are shown in Figure 1, and suggest that illuminance ratios are normally acceptable in the morning, excluding 27th of April and 22nd of December. In the afternoon, the ratios increase to be tolerable in general but beyond tolerable limits for 27th April, and the 22nd of December, March and September. Excessively high illuminance ratios occured on 22nd of December, March and September, and this can be assumed to be due to the influence of direct sun ingress. In terms of illuminance distribution, there were more than 50% of classroom positions where the illuminance levels did not meet the recommendations. The majority of the positions experienced less than 300 lux. Interestingly, the cases where illuminance levels mostly met the recommentations were the times when the sun's influence was most evident. It can be concluded that the classroom with the existing façade might require additional illumination in general. The direct sun may cause excessively high illuminance levels and unbearable illuminance ratios in the area next to the window at some specific times in the afternoon but it can also bring about useful amounts of daylight in the rest of the room. However, it was noted that applying the sunny clear sky conditions gave predictitions that appeared to overestimate daylight levels, particularly at the position beside the window.

Comparison of illumination levels in different façade types

For overcast sky predictions, most daylight levels did not meet the recommendations. However, it is obvious from Figure 2 (b) that the greater the overhang depth then the lower the daylight levels. For illuminance ratios shown in Figure 2 (a), the classroom with the existing window had excessively high illuminance ratios for all overhang depths, while the ratios for all cases in both fully glazed wall cases were lower than the tolerance scale. The optimization cases appear to have the most satisfactory ratios. It was also found that the ratios were all acceptable once the opposite wall of the window had been modified to be fully gazed. Moreover, some of the ratios in this group met the recommendations.

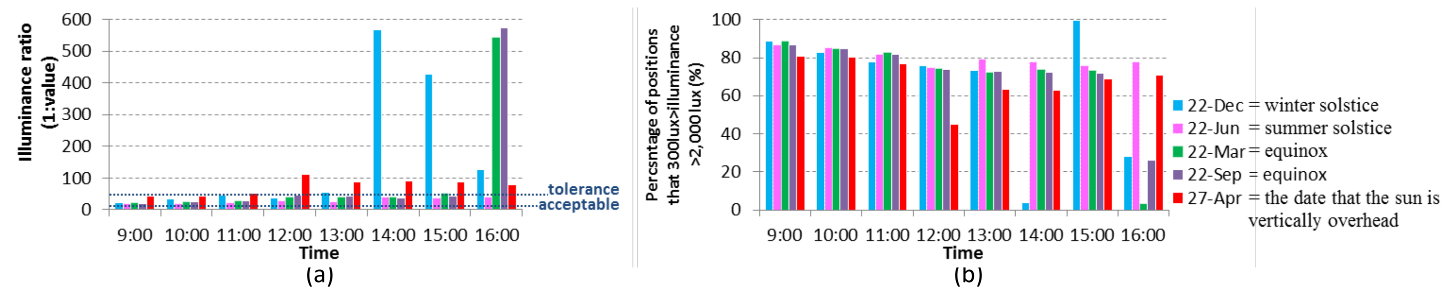

Figure 1 Variation of illuminance predictions of base case during working hour for a sunny clear sky (a) ratios of maximum to minimum illuminance and (b) percentage of room position to all while illuminance does not meet the recommendations

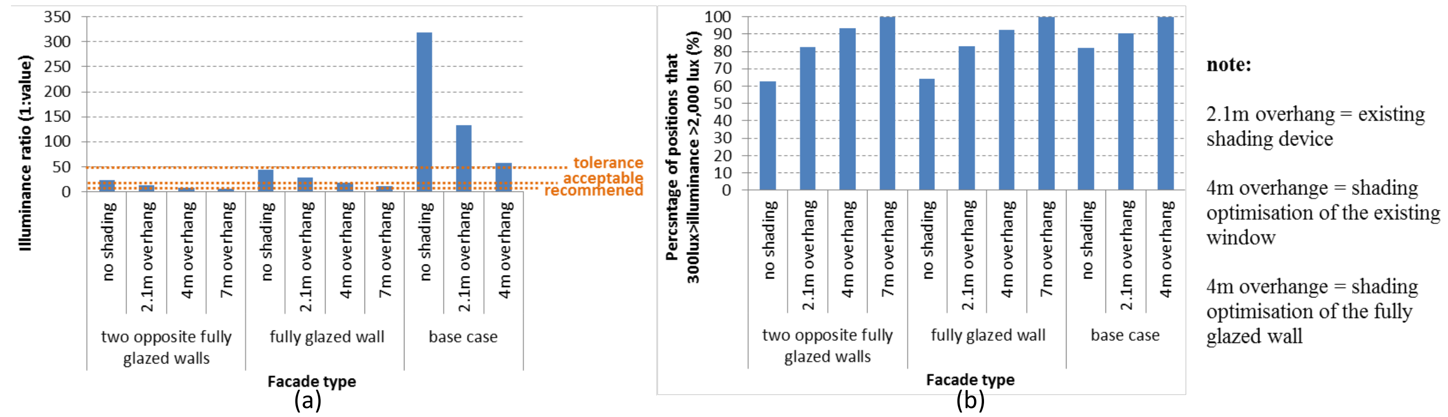

Figure 2 Comparison of illuminance predictions of 11 façade types for overcast sky (a) ratios of maximum to minimum illuminance and (b) percentage of room position at which illuminance levels did not meet the recommendations

INTERACTION OF LIGHTING LEVELS AND THERMAL DATA

For this interaction study, the relationship of overhang depth and window area will be presented for each indicator. The predictions at the winter solstice and the date when the sun is vertically overhead were selected, representing the coldest and warmest weather of a whole year. Generally, the predictions of total cooling load at the winter solstice were approximately equal to that on average for the year (Figures 3 (c) and 4(c)). For the warmest period, the cooling load was about 7-8 kW higher than average.

Overhang depth

All values for illuminance, PMV score and cooling energy requirement decreased as the depth of overhang increased (shown in Figure 3). The decreasing rate is high for in the case of the winter solstice while it is almost constant when the sun is vertically overhead. Without overhangs the illuminance levels and Fanger PMV scores seem too high for the fully glazed window types. Although the optimised depths of overhang may provide less cooling load and better comfort conditions, daylight levels never reach the recommended standard. The ranges of overhang depth that meet the requirements are 0-45% of 7m overhang for the existing window cases and 30-80% of full overhang for fully glazed wall cases.

Window type

Three types of window, consisting of existing window, one fully glazed wall and two opposite fully glazed walls, were studied. The highest differences between the existing window and fully glazed cases were approximately 1,300 lux for illuminance, 0.4 for Fanger PMV and 2 kW for cooling load. When one fully glazed wall and two opposite fulling glazed walls were compared, there was no significant difference of daylight levels but there were differences up to about 0.5 for Fanger PMV and 1 kW for the cooling load (see Figure 3). The cases of two opposite fully glazed walls also did not meet the neutral scale of the PMV model.

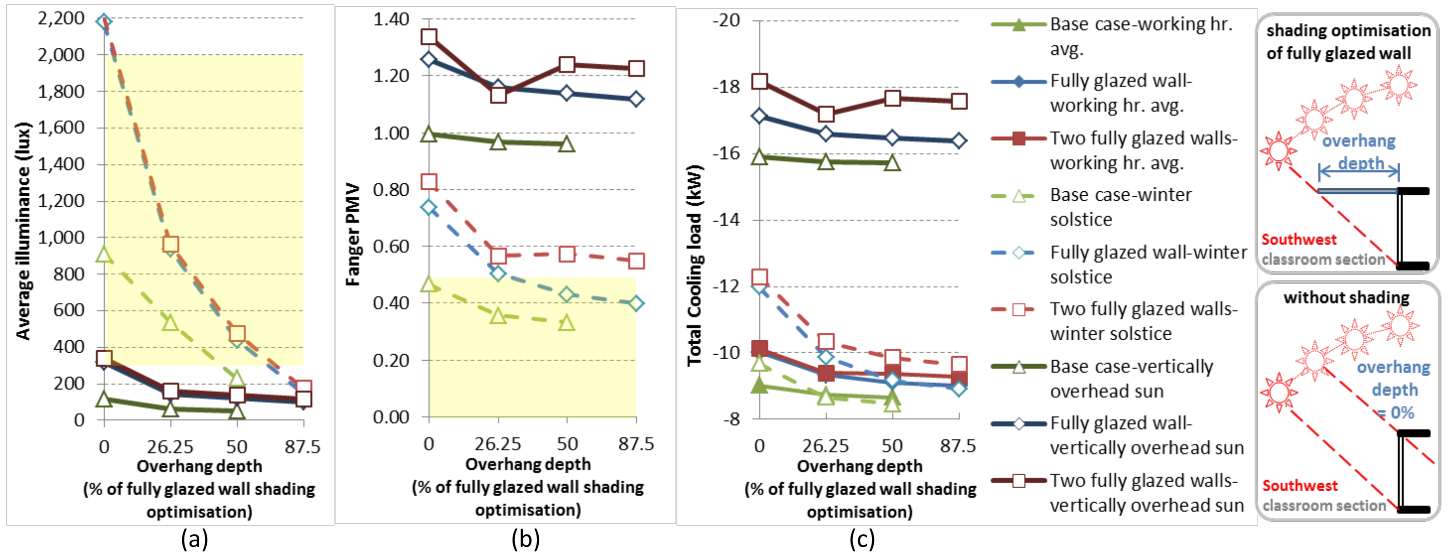

Figure 3 Decreases of illuminance, Fanger PMV and cooling load by overhang depth (a) Average of maximum illuminance, (b) Average Fanger PMV when air conditioning was operated and (c) Average of hourly total cooling load when air conditioning was operated in working hours during week days.

Window area

According to Figure 4, illuminance, Fanger PMV and cooling load all increase when the window area increases. The cases without an overhang have the largest rate of increase. The greater the overhang depth, the smaller the increase. Solar radiation affects the classroom in a negative way when the sun is directly overhead. Not only were the Fanger PMV and cooling load values considerably higher, but the illuminances levels were also inadequate in all cases. However, at the winter solstice four useful cases were found with both daylight levels and thermal comfort in the recommended ranges. The ranges of window areas that meet the requirements are 10-35% for the no shading cases, more than 18% for the existing overhang cases and more than 60% for the 4 metre-depth overhang cases.

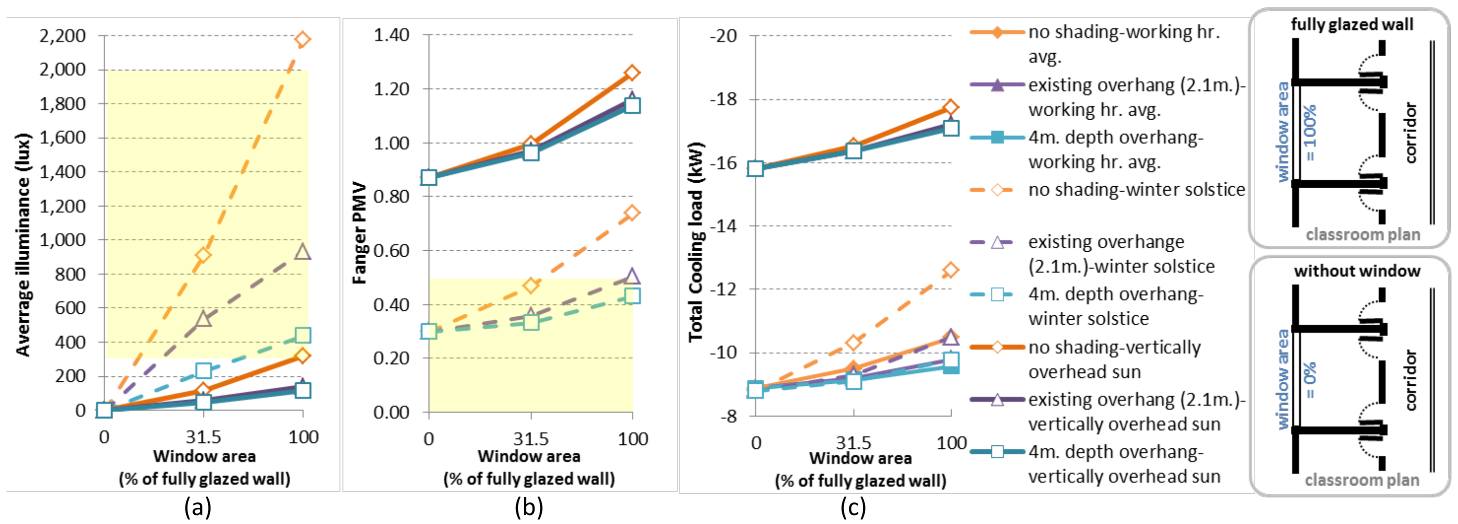

Figure 4 Increases of illuminance, Fanger PMV and cooling load by window area (a) Average of maximum illuminance, (b) Average Fanger PMV when air conditioning was operated and (c) Average of hourly total cooling load when air conditioning was operated in working hour during weekday.

DISCUSSION AND CONCLUSION

In general, it was found that daylight levels in the classroom were mostly not high enough even though the window area and overhang depth were improved. This problem arose from less daylight level being transmitted in to the room and its poor distribution around the room. It is probable that other innovative solutions could increase daylight levels and improve distribution.

The problems can be different if the façade is affected by a low sun altitude, such as at the winter solstice. Agreeing with previous research and the preliminary survey, direct sunlight possibly caused visual dissatisfaction in the classroom. The influence of the direct sun resulted in excessively high daylight levels in the area next to the window and overwhelming illuminance ratio values. This is due to insufficient shading devices for the southwest orientation in the afternoon. It appears that the window shading needs to be improved. On the other hand, when the thermal aspect was combined, the fully glazed wall without an overhang appeared to have excessively high illuminance levels and slightly warm discomfort voting, although high amounts of cooling energy were consumed. The optimal case of an overhang which can completely shade for direct sunlight was not suitable for daylighting. Interestingly, benefits from the direct sun were also found. Apart from the intense illuminance which affected the area next to the window, the low angle of the sun also influenced illuminance levls in the rest of the room. It is possible that this advantage is brought about by reflections of the transmitted solar beams. As a further solution, diffusing the direct solar beam might benefit unaffected areas – for example, using reflection techniques such as lightshelves. It appears that the impact of changing window area, compared to changing overhang depth, was more significant for daylight levels rather than thermal conditions. Their influences also were dependent on each other. In terms of illuminance ratio, the impact of overhang depth will be reduced if a large window is used. Similarly, the impact of window area will be high if there is no shading. It appears that the combination of full glazing on the opposite wall did not have much effect on daylight levels and, instead, resulted in higher heat transfer. However, the results show that this additional window provided more pleasant illuminance ratios. This strategy is, therefore, still useful for reducing variations in daylight distribution.

Generally, the 30-50% overhang depth and window areas more than 60% of toatal wall area are recommended. These ranges can be expanded when both parameters were specified - for example, a recommended overhang depth can be 0-50% for the existing window and 30-80% for the fully glazed wall. Unexpectedly, the existing façade, which was proved not to be practical, is also in the range. It reveals that those recommendations might be overestimates as they used the maximum average illuminance values. Consequently, the ranges will be examined and refined in the next stage of study.

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Impact of native evergreen trees on the visual comfort in an office space in Ahmedabad, India

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ABSTRACT

This study investigated the impact of native evergreen trees on the daylight availability in office spaces in Ahmedabad, India. An evergreen tree, native to the hot and dry climate of Ahmedabad, was selected and its impact on daylighting in interior spaces is analyzed compared to a no-tree scenario. The distance of the tree from the window was varied to examine parameters such as contrast and brightness at the task plane for the equinox and solstice days. Desktop Radiance 2.0, which is a backward ray tracing daylight simulation software, was used, followed by a calibration study. Uniform and sunny sky conditions based on Ahmedabad climate data were considered. The results indicate that trees can be very effective in achieving visual comfort in conditions of harsh sunshine outdoors. The type of tree is of more importance for visual comfort than the distance between the tree and the window. The evergreen tree performed well to mitigate visual discomfort. Careful selection of the tree type and its positioning on the southern facade reduced illuminance levels but helped improve visual comfort by almost 50%. This study also explains in detail the method used for determination of Leaf Area Index and Leaf Area Density used for calculating the crown density of the tree, which may help future work attempting to study the impact of vegetation on the thermal or visual performance of building envelope.

INTRODUCTION

Daylight is considered the best source of light for good color rendering. It gives a sense of cheeriness and brightness which is known to have a significant positive impact on people. Therefore, people desire good natural lighting in their living environments (Li DHW et al, 2006). Ahmedabad is located at 23°N latitude and 72°E longitude, in close proximity to the Tropic of Cancer. It, therefore, falls in a region that receives the highest annual rate of solar radiation. In such a harsh climate characterized by high levels of solar radiation and intense sunlight, appropriate design of windows is critical to minimizing direct sunlight by means of shading and providing diffused daylight reflected from the ceiling. Previous studies recommend using systems that can help to redistribute and filter daylight coming from windows and skylights. Shrubs and trees can achieve this in addition to providing other benefits such as pleasing aesthetics, noise reduction, and passive cooling (Khaled & Ahmed, 2012). Another study states that the shade from the trees reduces not only the direct solar heat gain through the building envelope but also helps to diffuse the light reflected from the sky and surrounding surfaces (Lechner, 2002). A recent study indicates that plants and trees can provide solar shading in the same manner as the *jalis*, *chajjas*, awnings, louvres while improving the quality of daylight by scattering direct sunlight and moderating glare the bright sky (Khaled & Natheer, 2009). Trees provide summer shade yet

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allow winter access. The best locations for evergreen trees are on the south and south-west side of the building. When trees drop their leaves in winter the sunlight can reach inside to heat the interiors (Kamal, 2012).

The penetration of daylight into a building depends on many factors, including the depth of the room from the window wall, ceiling height, internal reflectance value of the room surfaces, window orientation, shape and size, and the optical properties of the glazing. However, the most significant factor is the availability of daylight outside the building, which can be seriously affected by external obstructions like neighboring buildings or trees (Capeluto, 2003). Some studies such as of done by (Manglani, 2001; Gates, 1979; Reinhart & Jakubiec, 2012; Laband & Sophocleus, 2009; Yates & McKennan, 1988) have examined the effect of trees on the heating and cooling loads in buildings in various climatic types. These include quantitative and qualitative analysis of the effects of tree shading, evapotranspiration and wind control. The external radiative exchanges that took place between one tree and a west wall were studied. The study executed by (Manglani, 2001) proposed a methodology for collecting, analyzing and evaluating relevant data for the study of vegetation shade as a means of attenuating the incident solar radiation. The methodology consisted in collecting the values of solar radiation (incoming and outgoing), the air temperature, surface temperatures of the trees and the wall, both in direct sunlight and shade through field measurements and calculating the long-wave radiation flux.

Quantification and measurement of the role of trees in scattering sunlight and providing quality daylight in buildings is an area of research that has not been examined closely in the earlier studies. This paper aims to emphasize on the importance of tree shading and provides a methodology to analyze the effect of tree shading on daylight performance and lighting quality.

METHODOLOGY

Simulation Model

For the study, a room of 20m x15m, with fully glazed window of 3m x 20m on the southern facade and placing a mature evergreen tree (T_e) at 6m, 9m and12m one by one and comparing it with a no-tree scenario (T_n). Maximum distance of the tree from the window wall is calculated such that the highest point of the tree canopy makes a 45 degree angle with the center of the window sill. Diameter of the tree roots determines the minimum distance of the tree from the window wall. The minimum, maximum distances, and a mid-point between the two, are considered as three points for varying the location of the tree vis-à-vis the wall.

For glare analysis, a computer screen is considered as the reference point positioned at the center of the room at task level (0.7m from the floor), facing south (the vertical task screen faces the window while the user faces the wall) in one scenario and facing north (the screen faces the wall while the user faces the window) in the other.

A calibration study was also done using a 1:10 scale physical model of the office space, and the lux levels were logged on Mar 13, 2013 at hourly intervals from 0900-1800 hours at the 20 grid points shown in Figure 1. It was observed that from 0900 to 1800 hours the average deflection in the measurement ranges from 6-10%, with the measured readings being higher than the simulated values (Table 1).

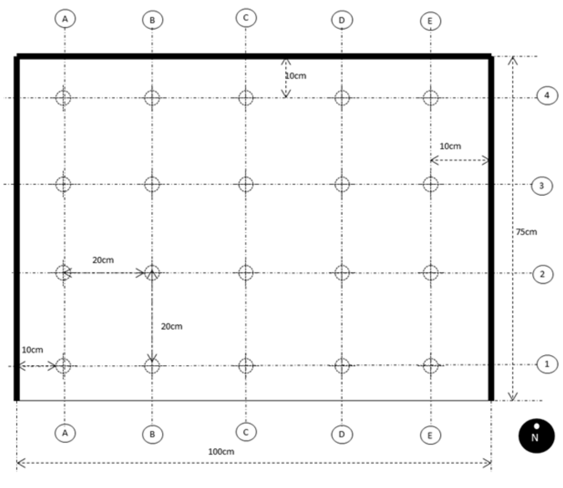
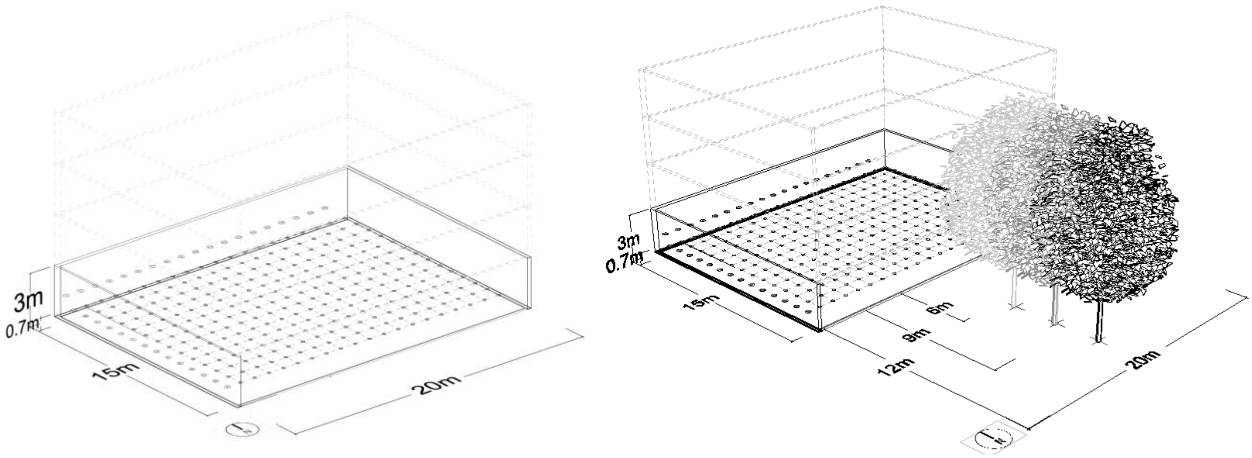


Figure 1: *Plan of the calibration model*

Table 1 Percentage difference between simulated and measured values

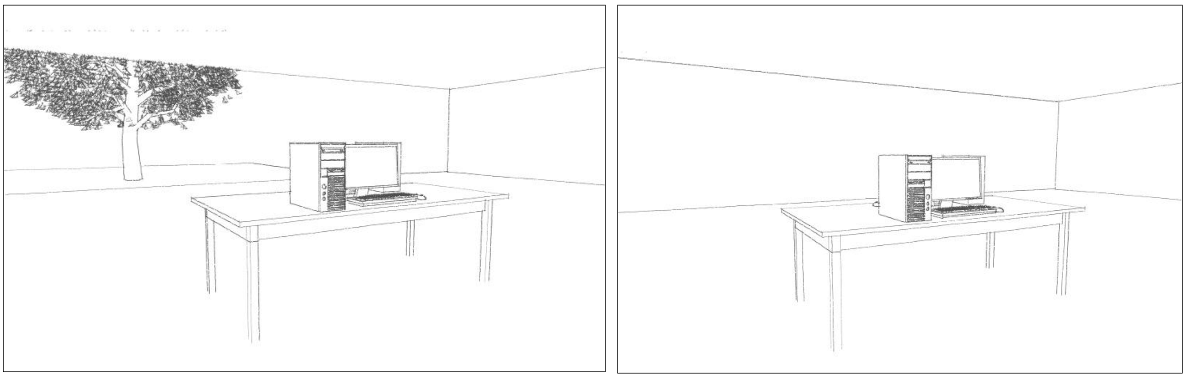
Sensor Points	Time (hours)									
	0900	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**
A1	10%	9%	13%	12%	13%	13%	11%	14%	13%	14%
A2	7%	8%	3%	3%	12%	13%	14%	6%	9%	12%
A3	12%	3%	3%	8%	0%	1%	1%	4%	1%	4%
A4	4%	3%	4%	4%	7%	2%	0%	2%	4%	3%
B1	13%	11%	14%	13%	11%	13%	10%	13%	10%	13%
B2	9%	7%	4%	6%	13%	4%	3%	7%	12%	10%
B3	11%	1%	3%	1%	8%	3%	6%	11%	3%	12%
B4	6%	1%	0%	2%	6%	0%	5%	3%	1%	4%
C1	12%	14%	15%	14%	12%	12%	10%	14%	11%	15%
C2	11%	9%	6%	8%	11%	7%	0%	5%	11%	13%
C3	11%	4%	1%	6%	6%	2%	5%	10%	5%	14%
C4	3%	3%	6%	1%	7%	0%	9%	5%	3%	3%
D1	13%	15%	14%	13%	12%	12%	11%	13%	9%	14%
D2	8%	10%	9%	9%	12%	5%	3%	5%	12%	11%
D3	2%	5%	4%	6%	5%	5%	4%	13%	6%	13%
D4	0%	1%	2%	5%	5%	2%	3%	4%	4%	4%
E1	11%	13%	14%	14%	11%	13%	10%	12%	11%	15%
E2	11%	10%	13%	7%	10%	8%	5%	8%	10%	14%
E3	4%	4%	3%	7%	3%	4%	6%	15%	3%	14%
E4	4%	2%	6%	3%	1%	4%	4%	8%	4%	5%



(a) (b)

Figure 2: *(a) Tn (= No Tree) view of the office layout with the analysis grid, (b) Te (= Evergreen Tree) view of the office layout with the tree placed at three distances (6m, 9m and 12m) from the building envelope*

Desktop Radiance 2.0 was used for daylighting simulation taking from similar studies (Khaled & Ahmed, 2012; Khaled & Natheer, 2009; Gandhi, 2011). Radiance uses accurate ray-tracing technique for generating an image by tracing the path of light through pixels in an image plane and simulating the effects of its encounters with simulated objects. In the first phase of the study, from a list of all native evergreen trees, one is selected. A simulation model was then developed with tree placement and task location, along with the appropriate material properties for a typical office space. Tree canopy density input was based on the analysis of actual trees. The precision of the 3D models was maintained by matching the canopy density between actual and modeled trees, and using the Leaf Area Density formula (Fahmy et al, 2010; Cantin & Dubois, 2011). Finally, the daylight simulations were run and the impact of tree type and its distance from the window was studied on illuminance, illuminance range and visual quality.



(a) (b)

Figure 3: *(a) T_n (= No Tree) interior view of the office layout with the analysis grid, (b) T_e (= Evergreen Tree) interior view of the office layout with the tree placed at a distances of 6m from the building envelope.*

The simulations were run for sunny sky conditions for Ahmedabad to account for extreme conditions. Test times are selected as representative of conditions during the year. The use of all or any two days of the equinox or two days of solstice are adopted widely by previous studies in daylighting research (Khaled & Ahmed, 2007; Khaled & Natheer, 2009; Hongbing et al, 2010). For this study, two equinox days of Mar 21 and Sep 22, and two solstice days of Jun 21 and Dec 27 are studied in detail. The standard daily office working hours in Ahmedabad are 0900-1700 hours. Simulations were run for 0800, 1000, 1200, 1500 and 1700 hours. Simulation inputs for building material properties and selected trees are described in Table 2 below.

Table 2 Material properties for simulation inputs

Objects	Properties
Walls, Window, Ceiling	White paint; Reflectance: 70%
Floor	White paint; Reflectance: 50%
Outside Exposed Ground	Green Grass; Reflectance: 34%
Glazing	10 mm Single pane clear glass with aluminum frame; VLT: 73%
Table and	Wooden brown laminate; Reflectance: 30%
LCD computer screen	Single pane black glass; Reflectance: 95%
Neem Tree	Canopy density: 60% (Mar 21), 70% (Jun 21), 80 % (Sep 22), 50% (Dec 27) Height: 12m; Crown diameter: 9m; Reflectance: 31%

Selection of Trees

References from literature (TCPO, 1980; Krishen, 2006) helped in developing specific criteria for selection of the appropriate tree type as follows:

- The tree should have the potential to scatter sunlight and improve lighting quality in indoor spaces; it should not block or significantly reduce illumination levels inside the space.

- It should be able to grow and withstand harsh climatic conditions of Ahmedabad with the maximum day temperature reaching as high as 50°C.
- It should be able to grow well in areas with mean annual rainfall varying from 400-1200 mm.
- The tree roots should not cause damage to building foundations, or, in other words, not extend beyond 5m of the tree spine for the purpose of this study

The tree selected for the study was *Neem* (*Azadirachta Indica*, henceforth referred to as T_e). T_e belongs to *fabaceae* family. It is a slow growing evergreen tree; the average height of the tree is 10-15m. The average canopy density ranges from 80-90% through the year. The tree is found in areas with mean annual rainfall as low as 300 mm (TCPO, 1980; Krishen, 2006).

RESULTS

Luminance contrast in the field of view should be comfortable and should improve the visual performance. The following luminance ratios within the field of view were used as the basis of evaluation: 3:1 between task and darker surrounding and 10:1 between task and remote darker surfaces (IESNA, 2000; CIBSE, 2008; Khaled, 2010; Khaled & Natheer, 2009; Khaled & Ahmed, 2007).

From Figures 4 through 7, it can be observed that T_e at a distance of 6m from the building envelope on Mar 21 (Figure 4) allowed UDI in a range of 62-94% under sunny sky conditions whereas on Jun 21 (Figure 5) the UDI range increased to 73-100%. UDI range on Sep 22 (Figure 6) was 75-95% and dropped to 34-86% on Dec 27 (Figure 7). After the T_e was placed at a distance of 9m from the building envelop, a slight decrease in the UDI range (49-94%) on Mar 21 was noted of useful daylight illuminance from 49%-94% under sunny sky condition, but increased to 72-100% on Jun 21. It was stable at 84-90% on Sep 22 and dipped again to 44-86% on Dec 27. When the distance between the tree and the building is increased to 12m, a UDI range of 65-94% was observed on Mar 21, 79-93% on Jun 21, increased to 86-100% on Sep 22.

On Mar 21 UDI was observed to be in the range of 0 -39% under sunny sky conditions when there was no tree in front of the window (T_n scenario) while on Jun 21 it to 0-42%. The UDI range on Sep 22 was 54-73% and Dec 27 was 30-61%.

Planting an evergreen tree in front of an office window in Ahmedabad T_e demonstrated about 50% higher UDI in the space for all the 4 days (Mar 21, Jun 21, Sep 22 and Dec 27) as compared to the no-tree scenario.

It is further observed that in case of T_n the daylighting levels are above 2000 lux for about 90% of the time in the month of March and June and almost 65% in the month of September and December, this leads to visual discomfort for the building users, on other hand plantation of tree T_e at multiple distances 6m, 9m, & 12m showcased that the daylighting levels are achieved well within the range of 100-2000 lux confirming visual comfort in the space, the unwanted solar radiations were reflected by almost 67%. UDI graphs determines that trees can provide sun shading and improve the quality of daylight entering through windows by scattering direct sunlight and reducing its intensity while moderating glare coming from the bright sky and confirms that sunlight can be filtered and softened by plantation of trees in front of the fenestration of the building envelope.

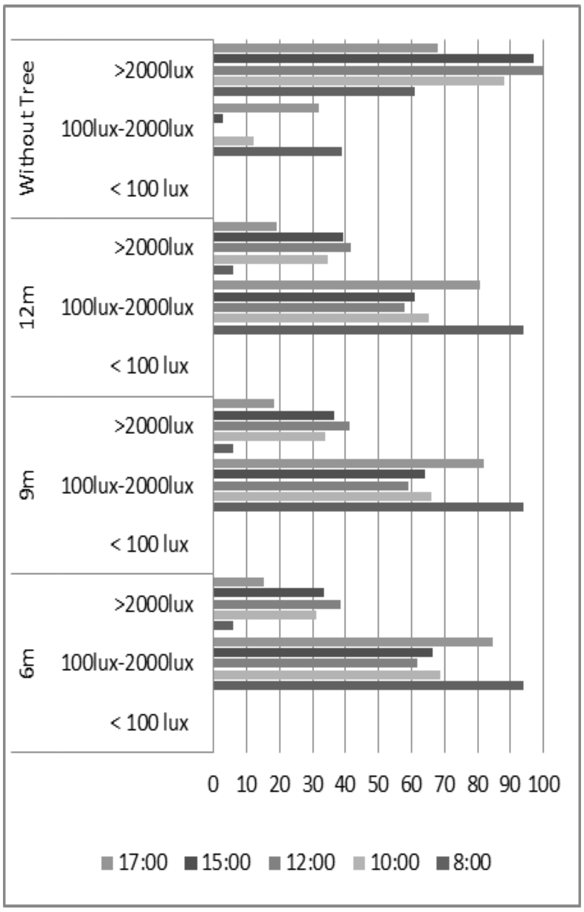


Figure 4: Useful Daylight Index, T_e on Mar 21

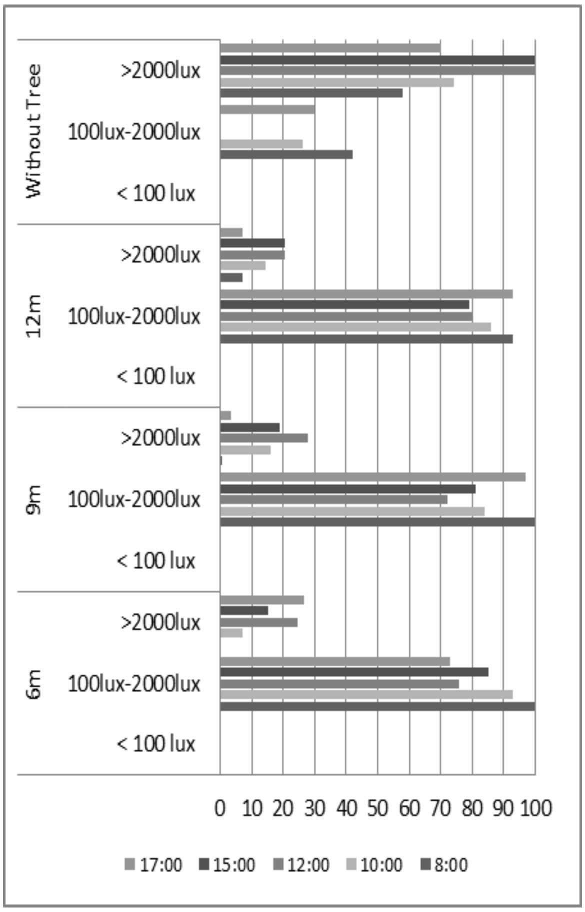


Figure 5: Useful Daylight Index, T_e on Jun 21

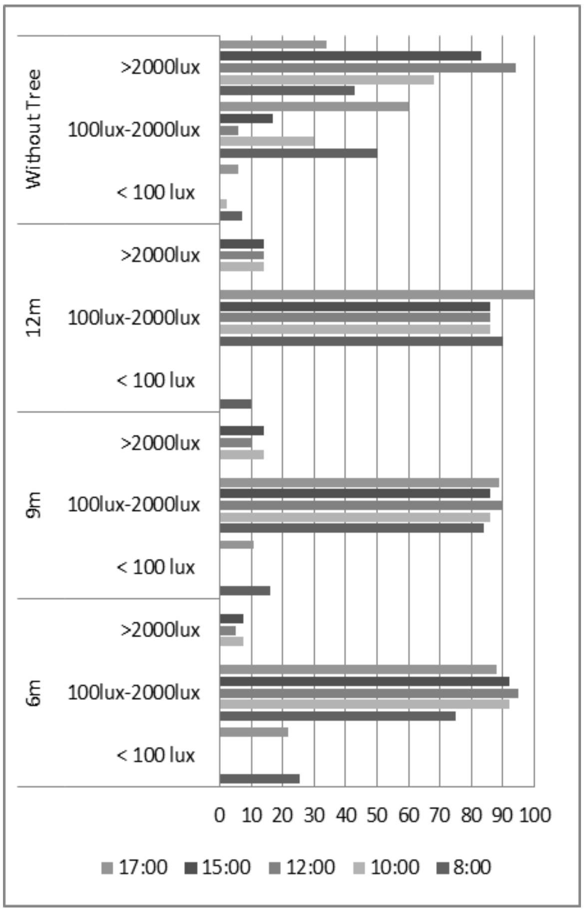


Figure 6: Useful Daylight Index, T_e on Sep 22

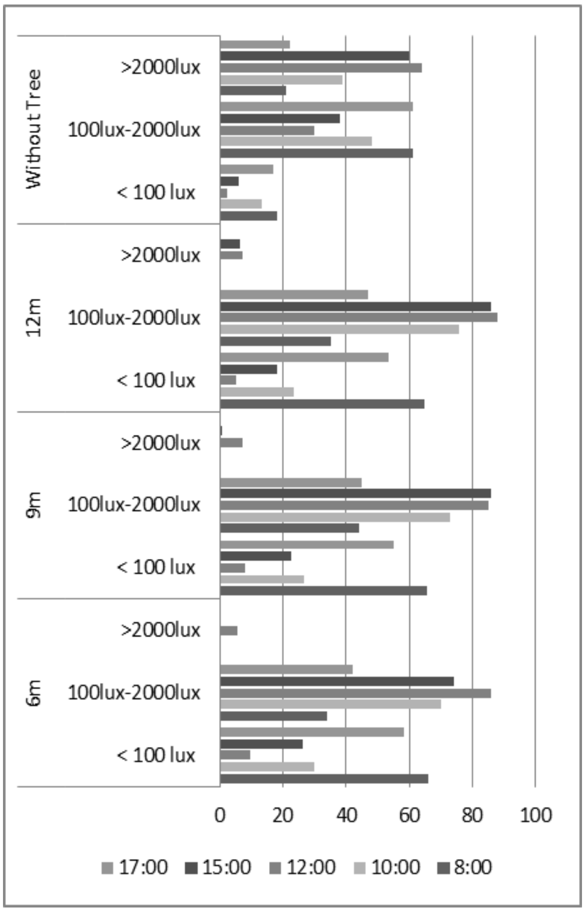


Figure 7: Useful Daylight Index, T_e on Dec 27

From Figure 8 (the upper bar "*yes"* is the time when visual comfort was attained and the below bar "*no"* indicates the situation when visual comfort was not achieved), it is observed that T_e when placed at a distance of 6m from the building envelope demonstrated visual comfort for most of the time on Mar 21 and Sep 22 as compared to Jun 21 and Dec 27. T_e at a distance of 9m demonstrated visual comfort for further more hours on Mar 21, Jun 21 and Sep 22 and when T_e was placed at 12m distance from the building envelop revealed that under sunny sky conditions the visually comfortable hours increased only for Mar 21 and Sep 22. The scenario where the user was facing the window (and the work screen was facing the wall) performed better on all four days as compared to that where the user was facing the wall.

For the T_n scenario in Figure 9, visual comfort was attained for very only a few hours on Sep 22 and Dec 27 under sunny sky conditions. For the rest of the time, both orientations of the work screen lead to discomfort.

It is evident from Figures 8 and 9 that T_e helped achieve better visual comfort and the desired contrast on the task screen as compared to the T_n scenario due to reduction in luminance distribution area between the luminance iso-contours. The luminance ratio between the task, nearby surroundings and remote darker surface satisfied the recommendations when the user was facing the window.

Thus it can be concluded from the figures 8 and 9 that trees have the potential to mitigate acute brightness of the sky perceived through the fenestration of the building envelope and reduce the contrasting luminance ratios, particularly at certain view angles to achieve visual comfort.

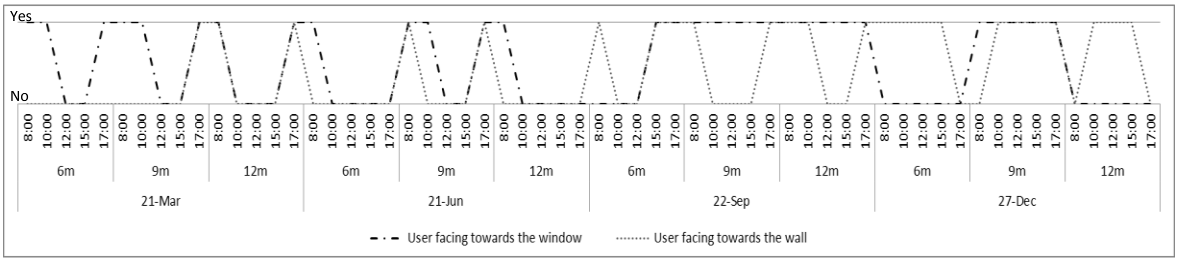


Figure 8: *Visual comfort for T_e scenario evaluated on the basis of the target luminance ratios*

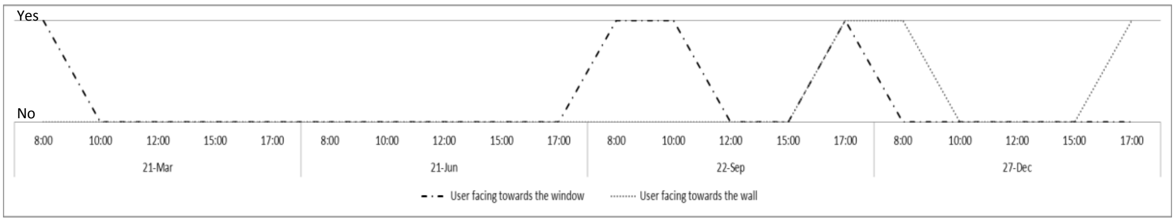


Figure 9: *Visual comfort for T_n scenario evaluated on the basis of the target luminance ratios*

CONCLUSION

Daylight analysis (luminance ratio and illuminance levels) for a typical office space in Ahmedabad brought to the fore three sources of visual discomfort: acute contrast in luminance between the task surface and background surfaces, high brightness from the windows, and uneven distribution of daylight in the space. Accordingly, it is suggested to plant native evergreen trees at a distance of 9m in front of the southern window to maintain the UDI within the range of 70-75% and provide visual comfort.

In future, a study of other types of trees, tree arrangements, and building orientation may be added for further study. It is also important to compare simulation results against actual measurements to validate the model, and develop more appropriate metrics to quantify visual comfort.

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NOMENCLATURE

T_e = Evergreen Tree

T_n = No Tree

UDI = Uniform daylight illuminance

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ABSTRACT

Sustainable buildings have to be comfortable, affordable, aesthetically pleasing and energy efficient with regard to their construction and operation. Lightweight buildings with integrated smart technologies can meet such ambitious goals. In order to demonstrate and analyse the potential of low-energy systems for such buildings, the 'Energy Efficiency Center' (EEC) was developed and realized by the Center for Applied Energy Research, Würzburg (ZAE Bayern) and Lang Hugger Rampp Architects, Munich. The building was inaugurated in June 2013. This paper covers the most important features of this innovative building and describes the performance of this forward-looking demonstration project.

INTRODUCTION

In December 2012, the Energy Efficiency Directive of the European Commission entered into force and has to be implemented by the Member States by June 2014. All member states are thus required to use energy more efficiently at all stages of the energy chain. Buildings in Germany are responsible for about 40% of the energy demand. It becomes clear, that the energy-efficiency and the use of renewable energies in the building sector have to be increased by a large degree. This includes the building stock as well as new buildings.

INTENT AND OBJECTIVES OF THE ENERGY EFFICIENCY CENTER IN WÜRZBURG, GERMANY

In order to support the development of low-energy buildings, the Center for Applied Energy Research, Würzburg (ZAE Bayern) started the realization of the research and demonstration project 'Energy Efficiency Center' (EEC) in Würzburg, Germany in 2010. The main objectives of the EEC were the implementation and demonstration of energy efficient cutting edge technologies, lightweight and highly insulating facades (with translucent aerogel modules, vacuum insulation, low-e coatings), textile roof construction (with daylight and climate control), innovative low exergy technology with implemented heat and cold storage systems (PCM components, passive infrared radiation cooling and open adsorption cooling technology), innovative daylighting and artificial lighting systems and an adaptive high-level control system, which ensures the most efficient interaction of the smart building technologies with the changing environmental influences. The combination of research, demonstration and dissemination of knowledge in one place is intended to generate the necessary boost for the fast implementation of energy efficient technologies in the building sector. Therefore the EEC can be seen as a highly dynamic driver for innovation which has the potential to achieve a maximum market impact and public visibility and therefore will accelerate innovation processes.

ARCHITECTURAL CONCEPT

In the Energy Efficiency Center, innovative, prototypical and energy efficient building materials, systems and technologies are implemented in order to verify and demonstrate a resource conserving building method. The building is part of a new development of a former military base next to the University of Würzburg at its campus 'Hubland' (Fig. 1).

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The main function of the building is to serve as a research and laboratory building for the 'Center for Applied Energy Research' (ZAE Bayern). It contains laboratories, an exhibition and information area and lecture hall on the lower floor (Fig. 2). The necessary offices are located on the upper floor.

The structural system is designed to minimize the amount of embedded energy (grey energy), while the performance of the building envelope is designed for maximum efficiency by using environmental energies for heating, cooling and supplying the building interior with a sufficient amount of daylight. With a high degree of pre-fabrication and the use of light-weight materials, the EEC shows exemplarily how the planning and construction process can control energy cycles in a positive way.

Fig. 1: Site plan of the EEC and its future surroundings

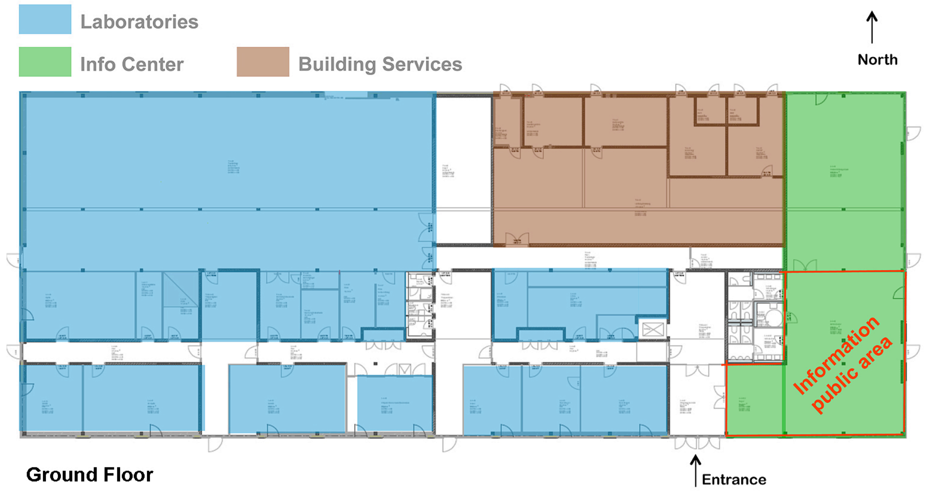

Fig. 2: Plan of the grund floor of the EEC

The building design reflects its innovative technical claim and became the flagship of the ZAE Bayern through its distinctive architectural concept. Being an integrated part of the thermal as well as the daylighting concept, the textile roof expresses its function through its unique appearance. (Fig. 3) The energy concept and the aesthetics of the building make a significant contribution to increasing the energy efficiency of the building and to enhancing the identity of its location for being one of the future hotspots for technological development in the field of passive and low-energy architecture.

Fig. 3: View of the Energy Effiency Center (south and east façade)

LIGHTWEIGHT CONSTRUCTION AND USE OF SOLAR ENERGY

The varied use of solar energy and application of lightweight materials as well as optimized construction methods are important elements of the building and its energy concept. The embedded energy for the production, transport and construction of the lightweight elements of the building envelope, the load-bearing structure and the inner walls and ceilings is in the range of about 1/3 if compared to massive construction methods. In this regard, the EEC's roof is the most significant architectural particularity in terms of the lightweight construction of the building. Its extremely light membrane structure serves as a weather protection against wind, rain and snow and forms the external boundary layer of the intermediate zone between the outer and the inner roof. (*Fig. 4, 5*) The space in between both roof layers acts as thermally preconditioned heat-insulating layer during the colder season. During the summer it is ventilated to avoid overheating.

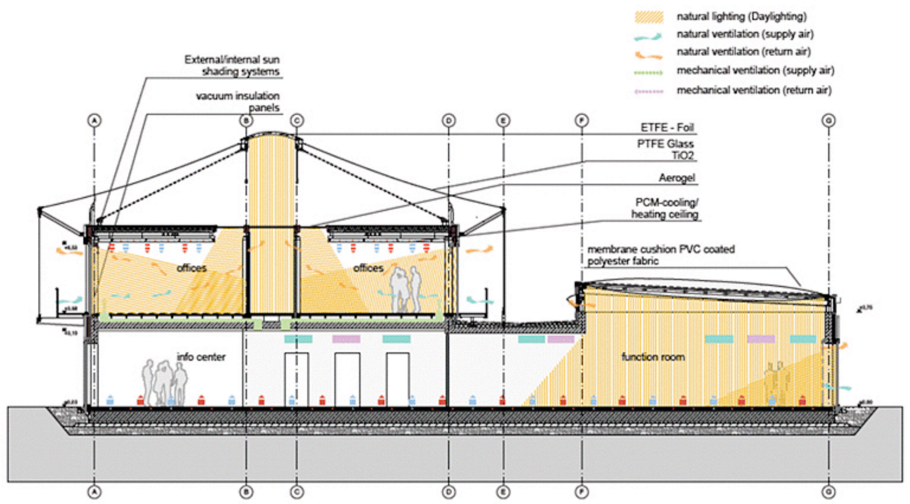

Fig. 4: Coss-section of the EEC showing the daylight distribution within the building

Fig. 5: Space between outer membrane and inner roof layer

The heat-insulating layer of the inner roof is consisting of different hard, panel-type materials, which were selected according to the required features and the installation situation. High-performance insulation materials, such as aerogel, follow the lightweight construction principle of the building. Exploiting the light transmission through the building envelope is of fundamental importance for achieving energy savings during the operation of the building. In residential buildings the energy demand is mainly related to heating and warm water supply, while in office buildings the demand for artificial lighting plays an important role also. In this regard, the translucent ceilings of the upper floor with its offices and interior corridors, improve the daylight autonomy up to 100 % throughout most of the building areas. In addition to the anticlastic PTFE-coated translucent glass fibre membrane of the double-storey building, the single-storey building on the north side of the main building has a translucent roof construction also (*Fig. 4*). It consists of a pneumatic, cushion-like structure, which has been realised as a frame structure under compressive stress. The upper and lower layers are made of PVC-coated polyester fabric. The thermal insulation of this roof construction consists of an integrated layer of translucent glass fibre material (thickness 10 cm), leading to a U-value of 1.0 W/m2K and a daylight transmission in the optimal range of 3%. The frames of these cushion-like panels are thermally separated.

In addition to the careful design and adjustment of the thermal properties of the roof construction, the exterior sun shading and internal glare-protection systems are optimized with respect to the solar geometry in order to provide optimal working conditions. Four different systems of sun shading have been employed: Glass-integrated micro louvers at the west and east facades were chosen to avoid excessive solar heat transmission during summer in the morning and afternoon. Furthermore adjustable aluminium louvers enhance the working conditions in the offices at the southern facade for different radiation angles. Especially for high sun angles, the overhang of the membrane roof provides excellent shading and reduces sky glare without obstructing the view from the inside to the outside. To avoid negative effects due to glare while working at the computer monitors, the office users can control their work environment by internal glare shields with a low-e-coated fabric to reduce radiation interchange.

The approach of a lightweight construction in combination with a highly insulating envelope has to be coupled with measures to enhance the thermal mass of the building to avoid extensive cooling/heating loads and control technologies. Therefore, in the EEC different thermal storage systems are integrated, i.e. two firefighting water tanks with 100 m³ each, wallboards with phase change materials (PCM), and heating/cooling ceilings with PCM. The applied low-exergy heating and cooling systems work with low temperature differences at a minimum temperature level. To provide the cooling for the regeneration of the PCM in a very energy efficient way, the ZAE-developed "Passive Infrared Night Cooling"-system (PINC) is connected to one of the firefighting water tanks. To support the passive cooling/heating of the PCM-ceilings, a new developed Liquid Desiccant Cooling system (L-DCS) provides cool or preheated, dehumidified air to the offices. These three innovative technologies and their interaction are described beneath.

PASSIVE INFRARED NIGHT COOLING (PINC)

As part of the fire protection system, the EEC has two water tanks with a volume of 100 m^3 each. These tanks are also used for thermal energy storage (TES). Both tanks are connected to the building's water cooling circuits by means of heat exchangers. One tank is cooled by a conventional compression cooler, the second one is connected to the 'Passive Infrared Night Cooling' system (PINC), which has been developed by the ZAE Bayern (*Fig. 6)*. In order to re-cool the TES, the contained water is pumped onto a separate area on the rooftop during night time, where the water runs freely over the slightly sloped rooftop surface and ideally cools down to dew-point temperature. The release of heat is reached by radiation exchange with the cold night sky, convection, and evaporation. This very efficient cooling method has been successfully in operation in the original ZAE building in Würzburg since 2000. An important aspect of this cooling system is the strong dependence between the cooling power density and the water temperature. Higher water temperatures lead to a higher cooling power density. Assuming typical water temperatures of about 18°C and the climate conditions in Würzburg, which is located in the southern part of Germany, a cooling power density of around 60 – 120 Wm^{-2} roof area can be achieved even in summer nights.

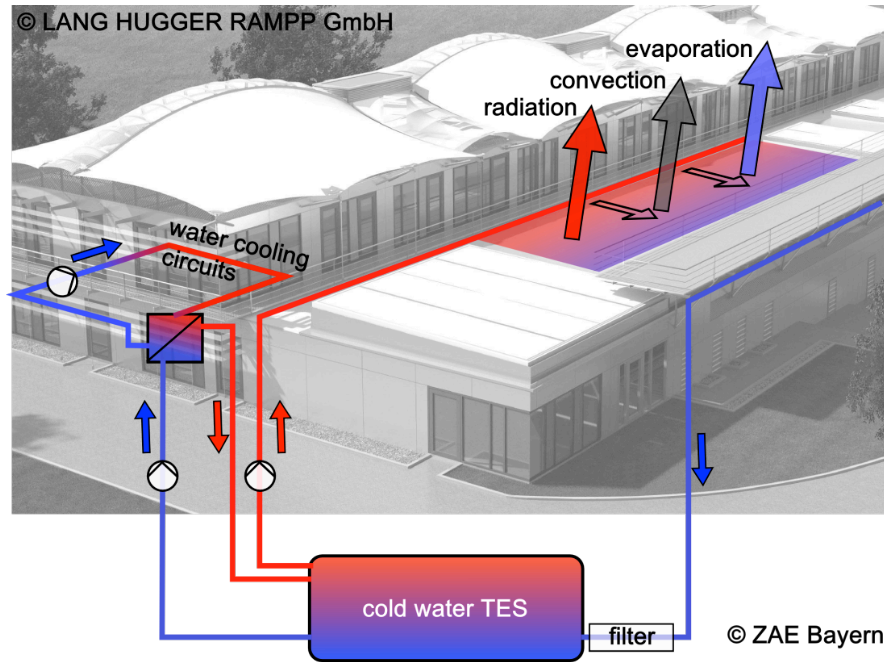

Fig. 6: Concept for Passive Infrared Night Cooling (PINC)

Electricity is only needed to transport the water, so a high COP (> 20) can be achieved. The cooling cycle typically lasts about 8 hours and yields a reservoir temperature of around 13 - 18°C. The storage volume is 104 m^3, the roof area is 300 m^2, the average cooling demand is 14.1 kW and the volume flow is in the range of 6 m^3h^{-1}. Evaporated water is replaced by rainwater collection.

As shown in *Fig. 7*, the graph illustrates the monthly sums of cooling energy generated by PINC subdivided into the parts evaporation, convection, and radiation, with radiation being the biggest part. In spring and fall nearly the complete cooling demand of the EEC can be provided by the system; during the summer months about 80% of the demand can be generated. As it is important to avoid freezing, the system will be disabled when the outside air temperature drops below 5°C. In consequence, the backup system (second tank and compression cooler) has to compensate the missing cooling energy mainly in the winter months (see the red-shaded areas).

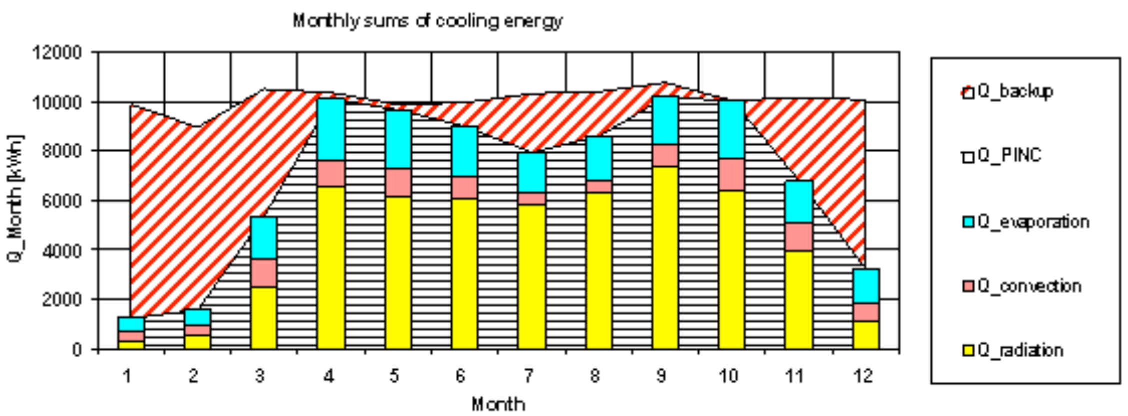

Fig. 7: Monthly sums of cooling energy generated by the PINC system

LIQUID DESICCANT COOLING SYSTEM (L-DCS SYSTEM)

Open cycle desiccant cooling systems can remove ventilation cooling loads of buildings very efficiently. These loads amount often to more than 50% of the total cooling load of a building. As it can be seen in *Fig. 8*, outside air is dehumidified in an absorber by a concentrated hygroscopic salt solution and subsequently cooled in an air cooler. The return air of the building is used in indirect evapoarative coolers to produce cooling water by evaporating water from wetted heat exchanger surfaces. The cooling water cools the supply air cooler and the absorber. The salt solution is diluted in the absorption process. In a regenerator, the solution is re-concentrated by evaporating water at temperatures of 70 to 80°C. The system of concentrated and diluted salt solution stores driving energy for this process very efficiently. The salt solution can be used as energy storage and transport medium. In winter the heat exchangers installed in absorber and evaporative coolers can be used as heat recovery system.

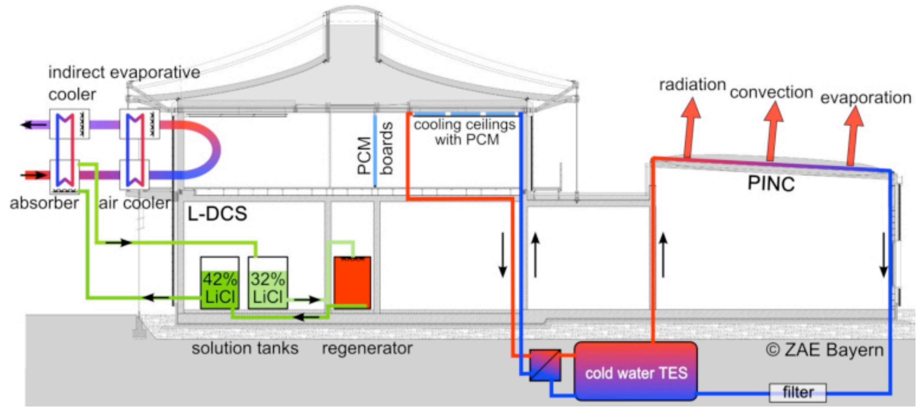

Fig. 8: Concept for Passive Infrared Night Cooling (PINC): Overview of the implemented innovative systems described in this paper and of their interaction. The L-DCS dehumidifies and cools warm outside air (or preheats cold air) for additional room temperature regulation. During this process, the salt solution gets diluted and has to be regenerated. The PINC system is used for cooling the cold water TES, which provides the required cold for appliance cooling and to regenerate the PCM implemented in the cooling ceilings.

PHASE CHANGE MATERIAL (PCM) FOR THERMAL STOARAGE

Due to its lightweight structure, the translucent building envelope, and the high internal gains, the EEC has an increased cooling load during summer time. To prevent an excessive temperature rise on warm and sunny days, phase change materials (PCM) with a high thermal storage capacity are integrated into the newly developed cooling ceiling construction as well as into the wallboards. The PCM undergoes a reversible phase change between the solid and the liquid state at a temperature of about 23°C. During phase transition a PCM can store a large amount of heat within a narrow temperature range as all absorbed heat is required to break up the bonds of the crystal lattice. With the PCM in thermal contact with the room air, this leads to a temperature stabilization effect, so temperature peaks are cut off. In combination with the effective shading system and supply air from the Liquid Desiccant Cooling System (L-DCS) no active cooling is needed most of the year.

To ensure the thermal effect of the PCM, it is necessary to solidify (i.e. regenerate) the material during the night. The regeneration of the PCM in the cooling ceilings is realized by a cooling circuit connected to the water tanks of the fire protection system. As the water in the tank is mainly cooled by ‘Passive Infrared Night Cooling’ this is a very energy efficient system. The regeneration of the PCM in the wallboards is achieved by convection. To predict the thermal effect of the ceiling-implemented PCM, a thermal building simulation was carried out with the program ESP-r. A detailed model of the south-west oriented office was implemented. The transparent façade areas are triple glazed; in the opaque elements vacuum insulation panels are integrated. Therefore a high thermal insulation is achieved by a thin wall construction. The highly insulating but translucent aerogel-module which is, in combination with the translucent membrane rooftop, providing natural lighting for the office, is also represented in the simulation model.

The cooling ceiling with an active area of 21 m² is equipped with 90 modules of macro-encapsulated salt-hydrate PCM with a mass of about 180 kg and a surface of 12.4 m². The inner walls are constructed of gypsum boards and insulation material.

The simulation was run using the test reference year weather data set for Würzburg, Germany, with extreme summer conditions. The simulation period extends from day 172 to 177 of the year, which corresponds to June 21 to June 26. A 14 day forerun was used to initialize the thermal starting condition of the room. As it can be seen in *Fig. 9*, there are high solar gains during the simulated days. The solar heat gains together with internal heat gains caused by electronic devices and the employees lead to a rise in operative temperature above outdoor temperature. When comparing the operative temperature curves of the room with and without PCM in the ceiling, differences in the thermal behavior of the room become obvious.

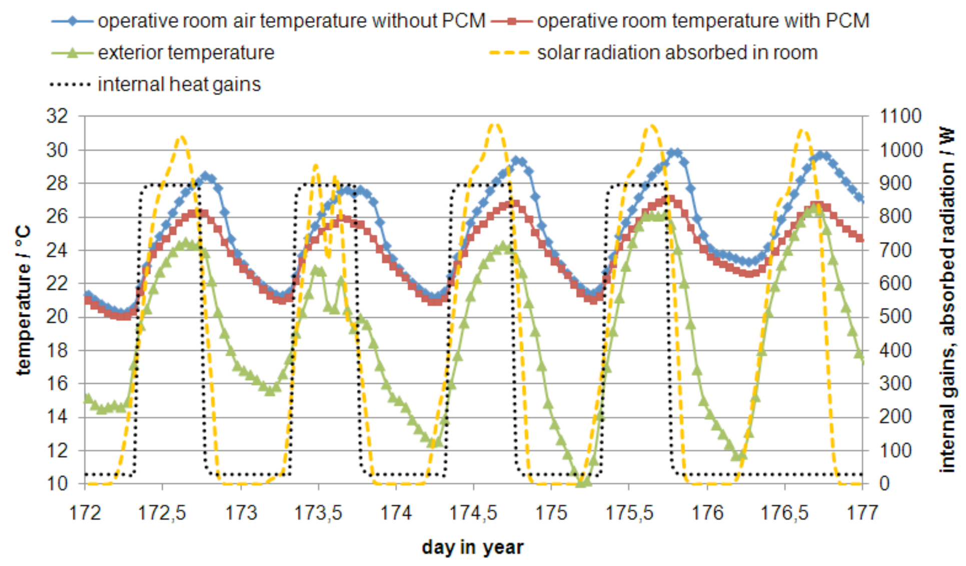

Fig. 9: Operative temperatures in the room with and without PCM in the cooling ceiling

Due to the good thermal insulation of the building envelope and the low thermal mass of the building, the rise in operative room temperature is significantly higher for the case 'no PCM' than for the case 'with PCM'. The PCM is able to dampen temperature fluctuations by storing heat during the phase transition.

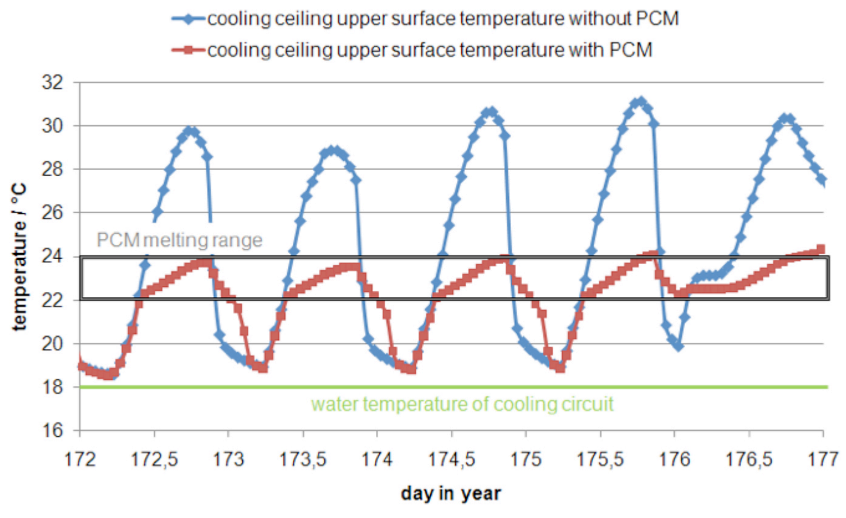

Fig. 10: Temperature of the upper side of the cooling ceiling (PCM-temperature for the case 'with PCM')

During the working time from 8 am to 6 pm the temperature "with PCM" rarely exceeds 26°C, so in most cases the temperature stays in the comfort range and no additional active cooling is required. Active regeneration is required to reliably solidify the PCM. The simulation shows that the PCM can be completely regenerated with cold water of 18°C during a regeneration period between 9 pm and 6 am (*Fig. 10*). To reduce energy consumption, no active regeneration is provided during the weekend (see e.g. day 176 in *Fig. 10*). In the EEC, the regeneration of the PCM will additionally be controlled by the buildings high-level control system. The control system uses a local weather forecast to ensure a demand-based regeneration of the PCM. If the weather forecast predicts a period of cold days for example, the PCM will not be regenerated actively in order to further reduce the energy consumption.

CONCLUSIONS AND OUTLOOK

As discussed during the introduction of this paper, a building has to be regarded as an integrated system, where all its various sub-systems and components, such as the building envelope, building structure, building technology and automation, are designed with their interdependencies in mind. To achieve this, an interdisciplinary approach with regard to research and design is essential to meet the proposed objectives of the presented project, as shown in the two examples for the energy storage systems (PCM systems and PINC), which were discussed in detail. These systems provide a substantial contribution to enhance energy efficiency. Since the EEC is constructed as a research and demonstration building, it serves as an ideal instrument for the further improvement and development of energy-efficient building solutions.

ACKNOWLEDGMENTS

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Session 1B : Low carbon cities and neighborhood development

PLEA2014: Day 1, Tuesday, December 16, 2014
11:30 - 13:10, Compassion - Knowledge Consortium of Gujarat

Achieving Best Practice Net-Zero-Energy Building Design Instruction Methods

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ABSTRACT

The United Nation's climate panel has published the third part of its long-awaited report on strategies for greenhouse gases (GHG) mitigation in 2014. The document by the Intergovernmental Panel on Climate Change (IPCC) considers the options for limiting or preventing GHG emissions and enhancing wide ranging activities that remove them from the atmosphere. For the building sector, numerous energy efficiency and GHG reduction market changes, new design and learning algorithms for more efficient simulation tools and benchmarking procedures have been developed. For example, the mandatory E.U. 'nearly Net-Zero-Energy-Building 2018 regulation' for all new public and privately owned buildings is now set up to help minimizing carbon emissions and reverse the negative impact. In the U.S., the American Institute of Architects (AIA) adopted the 2030 Challenge as a voluntary program, where participating buildings aim to achieve a 90% fossil fuel reduction by 2025, and carbon-neutrality by 2030. The following paper presents the outcomes from a funded project by the U.S. Department of Education under the topic of Building Literacy: the Integration of Building Technology and Design in Architectural Education. The funds supported the interdisciplinary development of a hybrid educational platform comprised of software and a hard copy textbook for advancing Net-Zero-Energy Building design. The most significant challenge was to select the best practice design variables for landscape and climate, building orientation and occupancy types, passive-active energy and climate control systems and their dynamic impact on each other. The paper will critically discuss and analyze the project implementation and the diverse feedback of multiple users from the profession and academia for further improvements for the second edition.

HYBRID PROJECT APPROACH

The instruction methods for both the book and the DVD "Best Practices for Sustainable Building Design" are developed for students, faculties, architects, engineers and everyone who is interested to apply best practice principles for Net-Zero-Energy Building designs (Figure 1). For instance, in today's struggling economies practicing architects are faced with lower in-service training costs. For that reason with better prepared graduating students, architecture firms will not have to incur the costs of providing technical training to new hires. This book with the DVD supports and promotes a self-directed form of learning, which not only is more effective than the traditional method, because it also offers greater flexibility and links to other online animation tools. The book and the DVD are structured into seven learning modules: landscape/climate and building form, building structure and envelopes, climate building control, renewable energy and lighting. The combined text and animation modules allow the user to quickly grasp the various, but interconnected concepts of passive and active strategies influenced by microclimatic conditions, building form, envelope materials and environmental

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control systems, and other elements, ensuring an accessible step-by-step learning process. The book and DVD animation project also addresses a number of critical international issues as it aims to significantly improve the effectiveness of teaching sustainable and net-zero energy efficient design within architecture programs. In particular, the originally funded U.S. - Building Literacy pedagogy is designed to increase students' comprehension, problem-solving capacity, and most importantly, ability to apply learned principles to carbon neutral design. The following diagrams are DVD animation excerpts about different Net-Zero-Energy building typologies in different climate zones within the Climate Control Module (Fig.1).

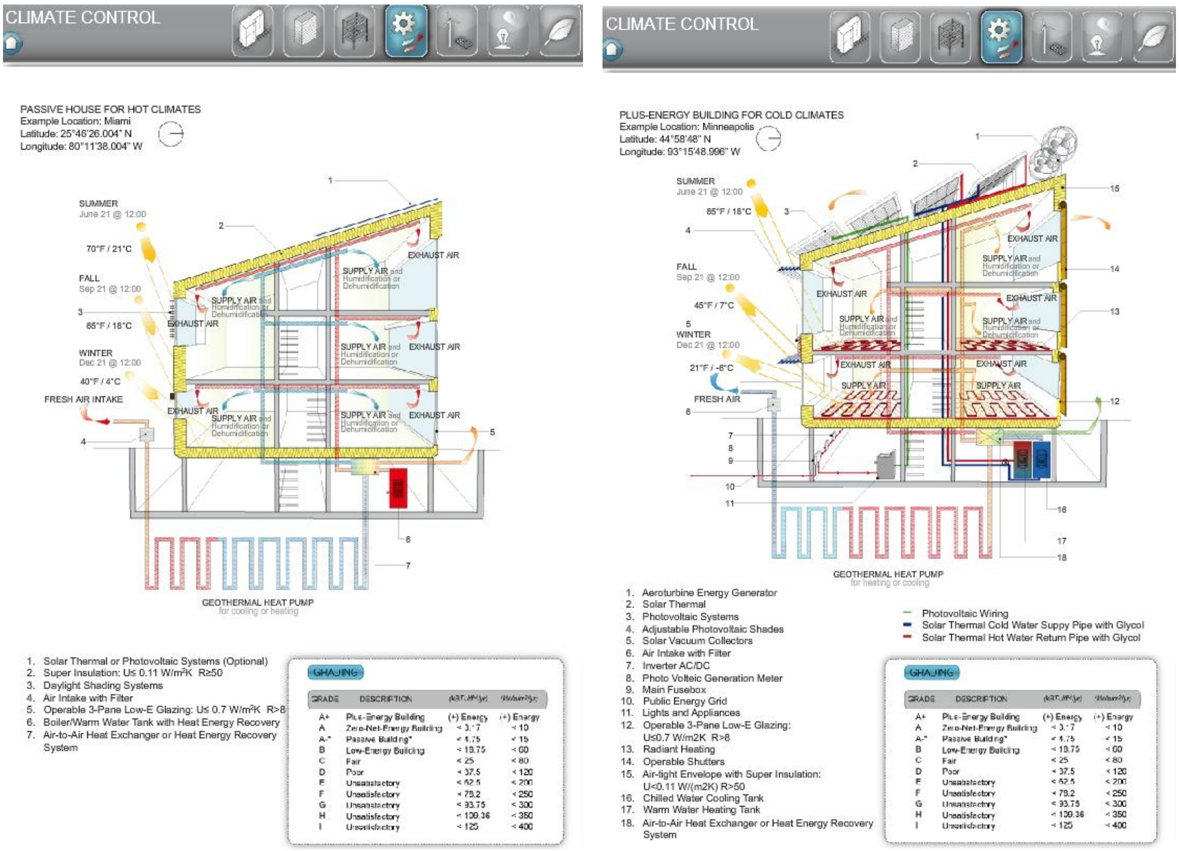


Figure 1. Excerpt of the Interactive Software: two Zero-Net-Energy building analysis tools for average hot and cold climates with passive and active building integrated renewable systems and their prospective Energy and CO2 per m2 a year performance. Source: Spiegelhalter/Ozer/Vassigh.

DESIGN VARIABLES AND TYPICAL SELECTION CHALLENGES

The book and software components of the educational framework have been developed as an immersive and integrated learning environment, delivering the content in a combined interactive format. Harnessing the capabilities of other advanced media, such as dynamic parametric modeling with other regular software tools, animations, interactive diagrams, and hypertext, the book DVD's software generated environment helps to visualize and engage concepts that may be difficult to grasp in traditional learning formats. The interactive content aims to engage and compel users to participate actively in the learning process. The inclusion of the software component also responds to the proclivity of the new generation of students who are more accustomed to accessing information in such environments. The software content is organized under a graphical user interface system that serves as a vehicle for learning on demand, linking to proper information quickly and easily. All the content of the book is cross-referenced to the accompanying software with graphic icons at important reference points. The icons are used to inform the user that there are interactive diagrams, charts, and animations explaining the subject in greater depth in the accompanying software (Figure 2).

The biggest challenge is posed by the selection of the design variables in context to the interconnectivity of building systems and their impact on each other. For example, how the selection of a certain type of cooling and dehumidification system will lead to maximum efficiency when combined with a particular structural thermal mass system, or how the choice of a specific structural enclosure system can affect the levels of natural lighting within the space and therefore impact the building's net-zero-energy profile. Since there are many building systems choices and a great number of combinations possible, leading students to learn about optimized solutions with so many variables and without a complex parametric computation seemed a difficult task to achieve. To face this challenge the authors had to limit many variables and choose strategically only those for general demonstration purposes (Figure 2).

Another significant challenge was the complexity of the architectural design process itself. Designing a building refers normally to a wide range of socio-cultural, aesthetic, and economical constraints. For example, to address the challenge that a sustainable building could be among one of the worst socially and culturally conceived buildings and may not work for the occupants at all. Although the authors had to make a decision to deliberately exclude all these other factors and limits the project expression of architectural form within the tool. However, these constraints still evolve and engage many of the authors and book/DVD user's discussions. The selection, development and organization of the entire content from various discipline areas of architecture, engineering and landscape architecture under one umbrella and providing instantaneous access to the vast amount of information occupied a significant amount of the project efforts. It is clear that not all topics could be covered as fore-mentioned.

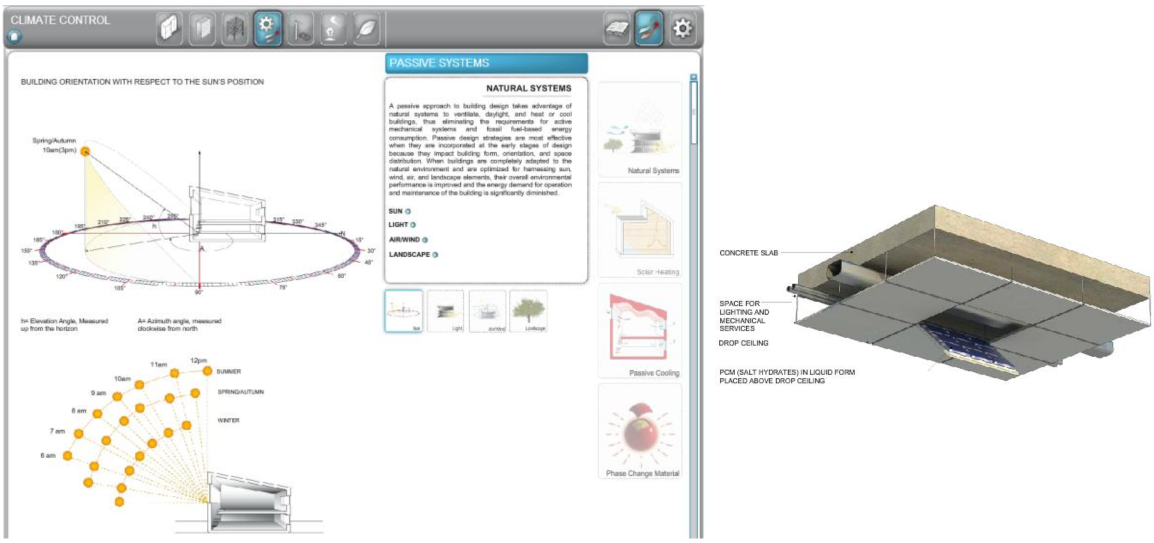


Figure 2. Screen shots from animations showing passive system choices on the left and one example of encapsulated phase changing materials as a pop up animation menu. Source: Spiegelhalter/Ozer/Vassigh.

BUILDING FORM AND ORIENTATION

Building form has a critical impact on the well-being of the users, resource use and on the water and energy consumption. The choice of form includes the shape, volume, mass, scale, and configuration of a building. Form should also support the requirements for the users' activities. Although building form may often be determined based on a number of other concerns outside energy efficiency and sustainability, selecting the proper form is one of the most important steps in net-zero-energy design. A properly conceived building form can mitigate the external climate in order to provide comfortable interior conditions, thereby reducing cooling, heating, ventilation, and electrical lighting demand. In particular, the building's environmental performance in relation to its formal configuration can be determined based on another number of factors including plan geometry, surface area to volume ratio, orientation, access to natural light, natural ventilation, and the location of the structural core and circulation spaces (Figure 3). The book software interface addresses these issues in each of the climatic zones of 1) Hot and Humid, 2) Hot and Arid, 3) Temperate and 4) Cool.

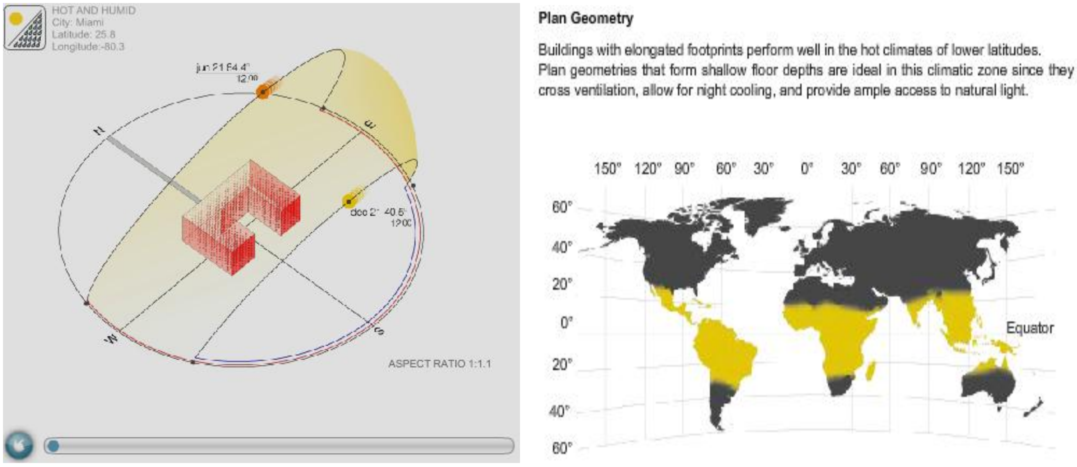
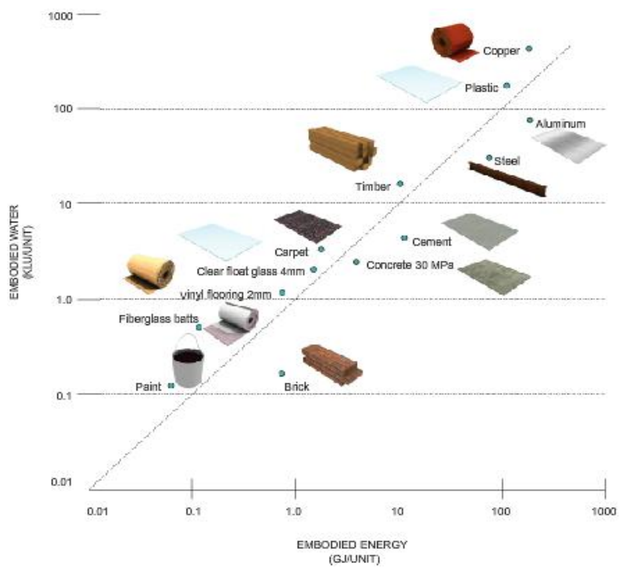


Figure 3. Screen shot showing thermal performance of a C-shaped building in a hot and humid climatic zone. Source: Spiegelhalter/Ozer/Vassigh.

BUILDING ENVELOPE AND THE LIFE CYCLE OF MATERIALS

The building envelope is the primary interface of a building with the exterior surroundings. As a result, the building envelope plays a critical role for the thermal comfort of the users and in the energy management and greenhouse gases emission mitigation. The proper selection of walls, roof and floor systems, construction materials and a rigorous, detailed development of connections and structural joinery are important components of thermal comfort, and water and energy saving strategies. In addition, thermal and moisture control, sound and fire insulation, and natural lighting strategies can significantly reduce dependence on mechanical climate control systems.



EMBODIED ENERGY TABLE

MATERIAL	EMBODIED ENERGY MJ/Kg	EMBODIED ENERGY BTU/lb
CMU Block	0.71	305.89
Mortar	1.40	603.16
Stucco	2.20	947.82
Brick	3.00	1,292.48
1/2" Gypsum Wallboard (Both Sides)	6.75	2,908.08
Recycle Steel	8.80	3,791.28
Glass	15.00	6,462.41
Steel	24.40	10,512.19
Metal Z Furring	24.40	10,512.19
Fiberglass Batt Insulation	28.00	12,063.16
Galvanized Steel	39.00	16,802.26
Flashing (PVC)	77.20	33,259.87
Weatherproof Membrane (Polystyrene)	86.60	37,309.64
Extruded Insulation (XPS)	88.60	38,171.30
Aluminum	155.00	66,778.23

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Figure 4. Screen shots showing the environmental impact in the use of materials for construction. The diagrams include embodied energy and water and the carbon footprint. Source: Spiegelhalter/Ozer/Vassigh.

The life cycle of materials entails the consumption of energy and water in their removal, manufacturing, transportation, maintenance and recycling and produce hazardous emissions during these processes. Approximate indicators of a material's environmental impact are embodied energy, embodied water and carbon footprint. Designing buildings with improved environmental performance should go beyond decreasing the operational energy, and aim at reducing embodied energy, embodied water and carbon footprint during the life cycle of building materials.

BUILDING STRUCTURES

Selection of structural materials and systems for buildings is often based on material efficiency and reducing the structural components to the smallest possible size without compromising safety. Although this process promotes effective use of natural resources, other strategies that utilize materials with high-recycled content and reduced impact on the environment are significant ways in which the structure can become more effective in reducing the buildings' carbon footprint. The concepts of structures are summarized to 1) Structural materials and their properties, 2) Horizontal Spanning Systems, and 3) Vertical Spanning Systems (Figure 5).

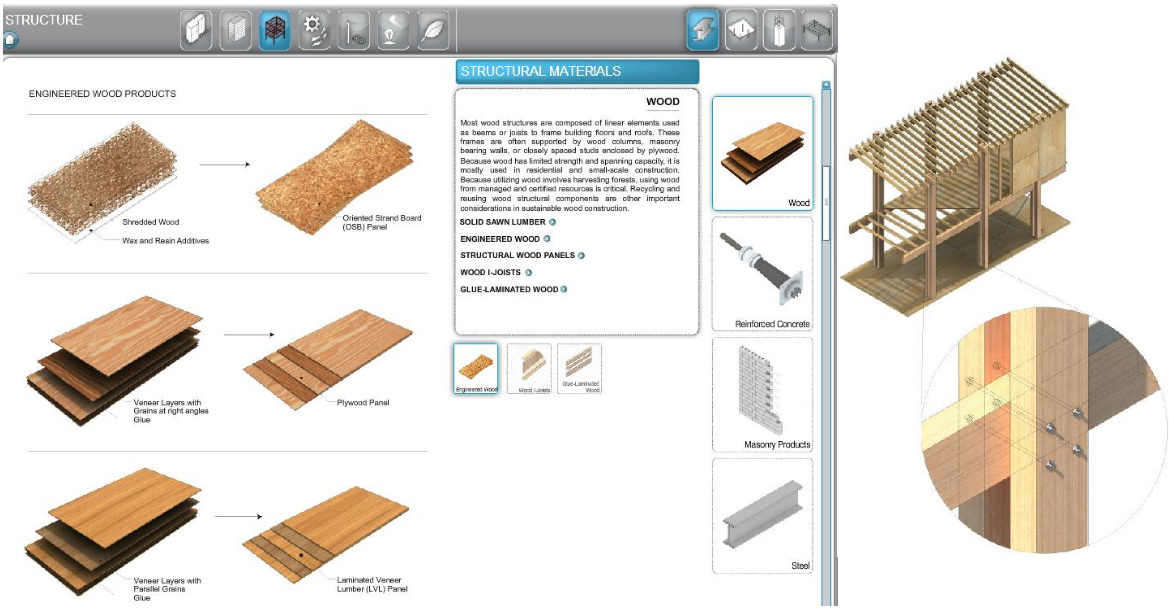

Figure 5. Screen shot showing a wooden structural materials and frame systems. Source: Spiegelhalter/Ozer/Vassigh.

CLIMATE CONTROL SYSTEMS

Designing resource efficient buildings with active, passive or hybrid means of achieving comfort requires a thorough understanding of climatic conditions, building occupancy types, and the availability of resources. Although there is a wide range of mechanical means for controlling the interior conditions of buildings, they present significant drawbacks to the natural resources and the environment.

While it may be unrealistic from case to case to completely move away from the active methods for climate control, investigating passive means of ventilating, daylighting, heating and cooling buildings are critical (Figure 6). The book texts and software categorizes the passive climate control systems into: 1) Natural Systems, 2) Solar Heating, 3) Passive Cooling, 4) Phase Change Materials, and 5) Building Insulation. The study of active climate control systems includes: 1) Production Systems, 2) Distribution Mediums, 3) Distribution Methods and 4) Recovery Systems.

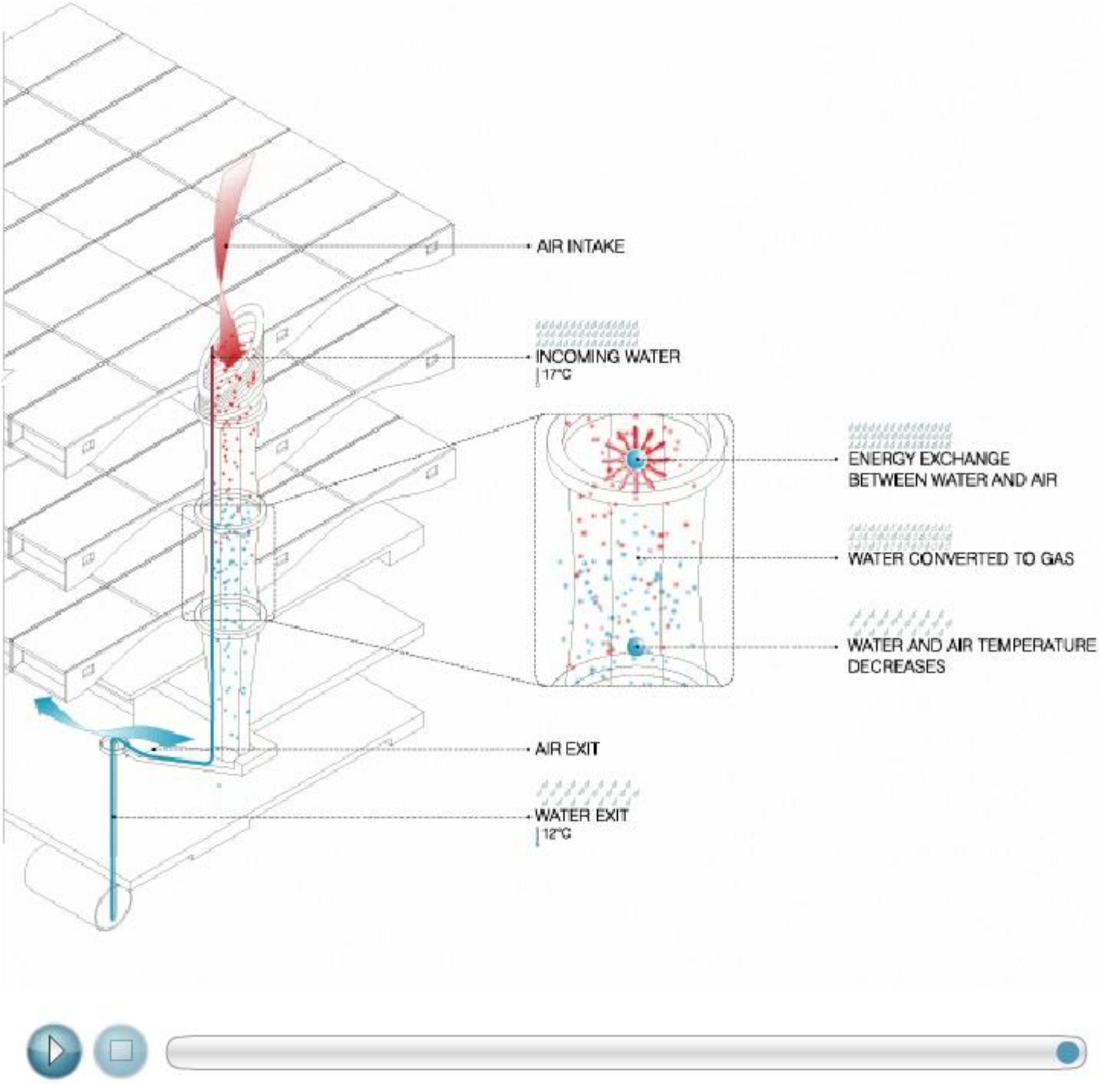

Figure 6. Screen shot of an animation showing a latent heat process and energy exchange cycle. Source: Spiegelhalter/Ozer/Vassigh.

RENEWABLE ENERGY

Fossil fuels are non-renewable as they draw on finite resources that are diminishing. These fuels are becoming increasingly more expensive and produce irretrievable damage to the environment, and with that impacts, as well, human health and the survival in climate change threatened societies. In contrast, renewable energy resources are constantly replenished and their capacity to replace conventional fuels has significantly increased during the past decade at the global scale. In its various forms, renewable energy sources include natural elements such as sunlight, wind, biomass, tides and geothermal heat.

Energy harnessed from these elements can be used to produce electricity, heating and cooling energy for buildings operations. The book software investigates selected renewable energy forms in five modules of 1) Solar Thermal Convection, 2) Photovoltaic Systems, 3) Wind Energy, 4) Geothermal Energy, and 5) Energy Storage Systems. Biomass is not included and will be integrated in the next book edition.

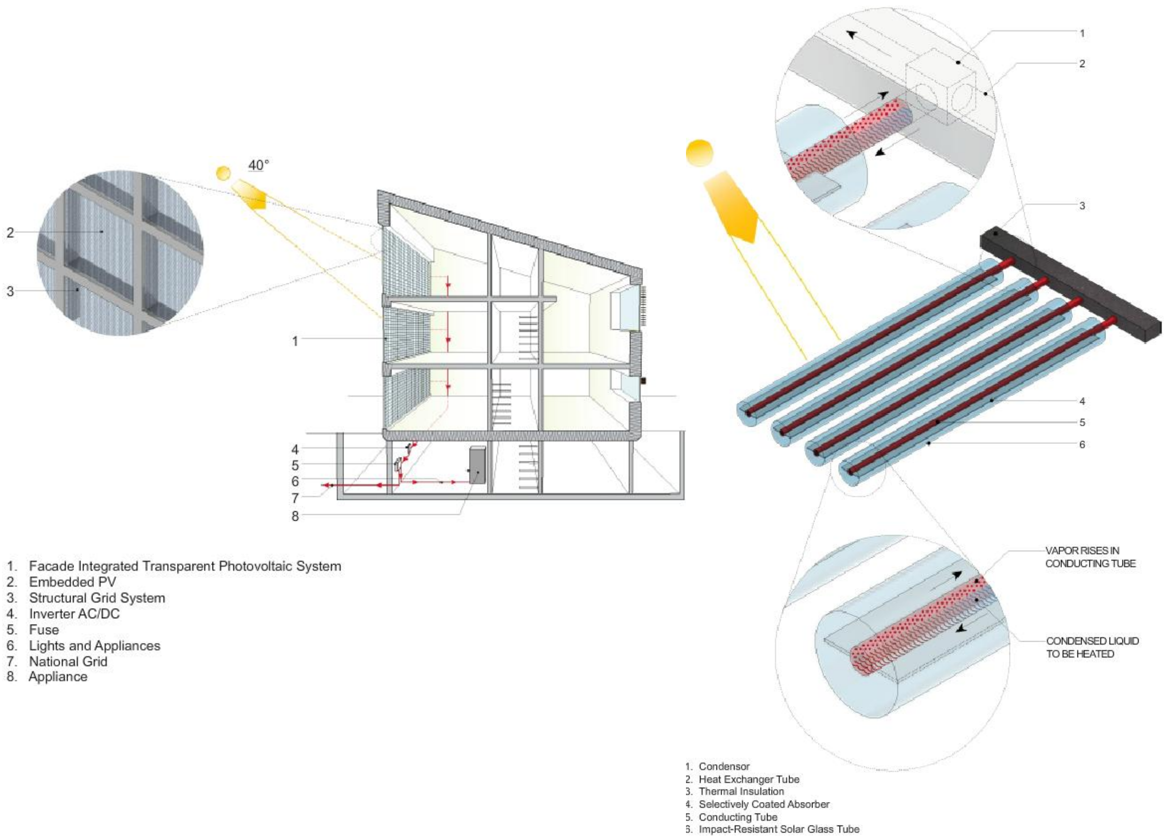

Figure 7. Screen shots from animations showing, a) solar façade integrated photovoltaic system. b) heat pipe conductor. Source: Spiegelhalter/Ozer/Vassigh.

NATURAL AND ARTIFICIAL LIGTHING

Since thousands of years architecture has embraced natural lighting as an important component of spiritful, healthy and inspiring aspect of buildings. Combined with daylight control systems, effective daylighting also saves energy and avoids greenhouse gases. It is well-known but not often practiced and implemented in building designs that bright, ambient living space or workplace can improve quality of life, improve user productivity and reduce buildings' lifecycle cost, while minimizing the adverse impacts on the environment. However, using natural light as the only source of illumination is not always possible and various levels of artificial lighting are often required per occupancy type and specific building code requirements.

The use of artificial lighting in buildings can account for a significant portion of the buildings' electric energy consumption. Using artificial lighting strategies with occupancy sensor infrastructure technology, dimmable efficient lighting systems and control devices, can reduce the electric energy demand significantly. This section therefore divides the study of light into natural lighting and artificial lighting.

The book software organizes the study of natural lighting into seven modules; 1) Day Lighting, 2) Glazing, 3) Climate zones, 4) Side Lighting, 5) Top Lighting, 6) Light Shelves, and 7) Light Redirection Systems. The Artificial lighting modules include; 1) Light sources, and 2) Zoning by light.

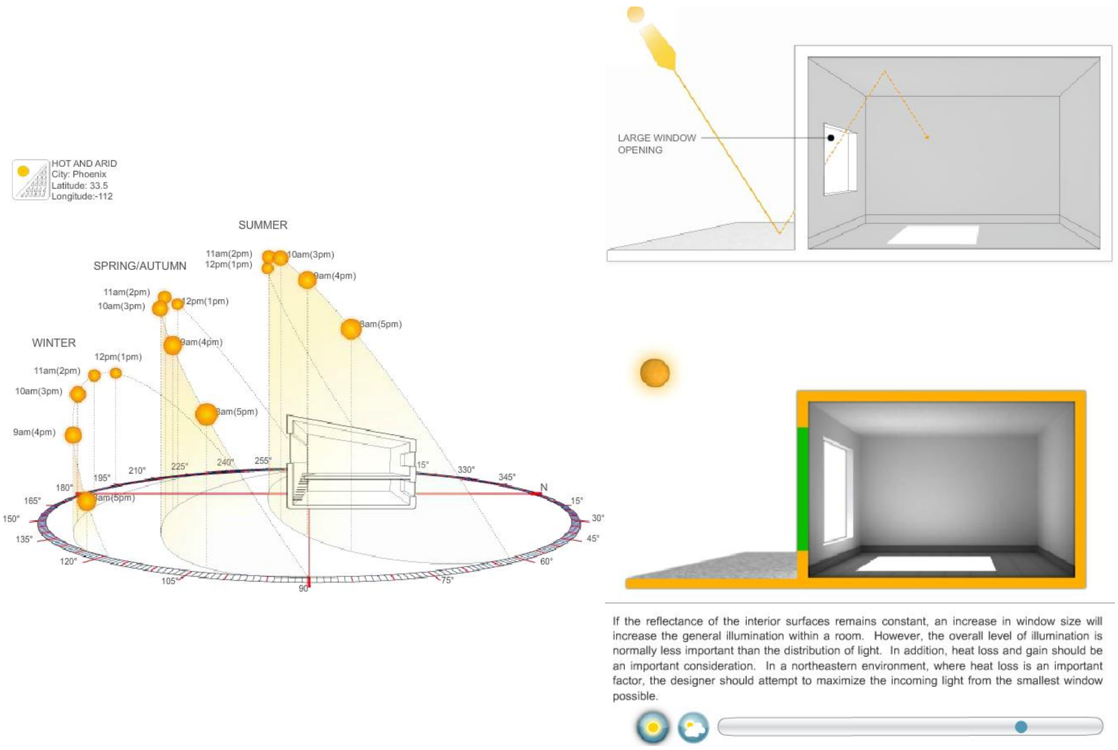

Figure 8. Screen shot showing the concept of sun light angles and paths with in relation to window sizes, room geometries and surface reflectances of the choosen materials. Source: Spiegelhalter/Ozer/Vassigh.

LANDSCAPE DESIGN AND SYSTEMS

Landscape design should be considered as an essential and integral component of a holistic approach to sustainable net-zero-energy building design. Landscape elements and systems have a major impact on water, energy and resource management. Remarkable reductions in non-renewable resources consumption can be realized within a building and in its surrounding site by simply using landscape elements for the avoidance of heat islands, mitigation of heat transfer through shading and increase of natural ventilation strategies through soft cape designs with temperature and pressure differences. The book software interface organizes landscape systems into four major segments: Concepts, Thermal Efficiency, Hyrological Efficiency and Case Studies. The segment Thermal Efficiency concentrates on the effective use of landscape elements to mitigate climatic conditions in building projects.

Figure 9. Screen shot showing the impact of urban heat islands in different climate zones and different surface materials and plants. Source: Spiegelhalter/Ozer/Vassigh.

CONCLUSION AND OUTVIEW

The project outlined describes a step-by-step pedagogical platform designed to teach basic resource conservation and concepts for designing carbon-neutral or nearly net-zero-energy buildings. Perhaps the real strength of the platform is the combination of book and interactive software formats. The funded project by the US Department of Education required a summative and formative project evaluation. This was accomplished through a component collected responses from the project team, faculty, and participants during the project development phase and beta testing. The information was used to provide feedback to the authors in order to improve the project. The summative evaluation measured the effectiveness of the software by analyzing comparative student performance at the State University at Buffalo (UB) and Florida International University (FIU) from 2009 to 2012. In all those tests, the animation DVD helped to visualize and engage with the exposed concepts that may otherwise be too ambiguous, too boring or too difficult to comprehend in only a text-image book format. In summary, the results showed all experimental groups exposed to the software pedagogy and tool displayed statistically significant improvement between entry and exit test scores, while the control groups not exposed to the tool showed no significant improvement. The future work to improve the next edition will include more interdisciplinary testing methods and educational games with interactive quizzes.

Another emerging question for improvement is how the future of academic and professional education will change when it comes to the increased usage of text/web-based software for tablets versus textbooks. The benefits are clear, that text/web-based software for tablets can store and process more learning materials than textbooks. Most tablets today have memories between 20GB and 100GB, which can hold hundreds of thousands of textbooks. This means a single tablet is more than capable for holding all the textbooks a learner needs plus animations, quizzes and homework. This poses the critical question if we then still need physical text books in the future? Will this lead to a fundamental paradigm change in education and practice? What are the disadvantages of digital learning with tablets and other handheld devices? Some say there are a number of health issues caused by the heavy usage of tablets: eyestrain, blurred vision and headaches, to name a few. These are symptoms which are collectively known as Computer Vision Syndrome. Or others observe disadvantages in the use of tablets that students who use them tend to get too distracted, as opposed to those who use textbooks. Some state that distractions are related to digitally connected students who are simultaneously into games, videos, emails and countless entertainment applications while they are in a learning environment. In summary, all the fore-mentioned and perhaps many more constraints would be worthwhile to further investigate to improve the pedagogy of "Achieving Best Practice Net-Zero-Energy Building Design Instruction Methods."

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A LOW ENERGY COMMUNITY? A comparative study of Eco-Villages around the world

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ABSTRACT

This paper investigates what is being done to produce sustainable community developments to minimize ecological footprint. Five international case studies were compared with the Govardhan Eco Village in Maharashtra, India. The study describes each case study and then looks at how various sustainable principles have been integrated into the community. Each case study was compared to an appropriate set of sustainability indicators to see which parameters were addressed. In order to establish the fundamental sustainable design focus of each case study, whether technology or human behaviour, the analysis looked at the types of parameters governing each project. Results showed the parameters incorporated in the case studies did not obviously change with time. Further scrutiny of the parameter matrix for all case studies suggested two distinctly different trends in the 'eastern' and 'western' examples. The Indian example appears to show true sustainable development, relying less on technology and more on human capital.

INTRODUCTION

As identified by Holling (2000) and substantiated by Ewing and Moore (2010) there is growing awareness of the massive changes that human societies are causing to the environment, implying a need for a fundamental change in lifestyles (Holling 2000). In 1987 the Brundtland Report, *Our Common Future*, first defined Sustainable Development as human development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987) and supported policies such as the adoption of the Kyoto Protocol; the founding of Agenda 21 (agenda for the 21st century) in 1992; and the 1997 formation of the Global Reporting Initiative (GRI). A more recent populist influence was the film, *An Inconvenient Truth*, by former American Vice President Al Gore (Gore, 2006). Most energy consumption and pollution originates in the lifestyles of the citizens of developed countries (Mithraratne, 2013) and this has caused some members of the architectural profession to rethink design principles, resulting in new 'sustainable' developments, as discussed here. The 1992 Earth Summit in Rio de Janeiro led the way by outlining a set of actions for sustainable development, Agenda 21(United Nations Environment Programme, 1992). To implement this, the United Nations instituted a "set of indicators of sustainable development" to monitor progress (Bell and Morse 2008).

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PROBLEM STATEMENT AND OBJECTIVES

Reducing energy use in new and existing buildings is an urgent necessity. Energy consumption in the building sector is more than one-third of national energy use in India (CARBSE 2014), and with further growth in this sector, India, along with other developing countries, faces a formidable challenge in reducing its dependence on fossil fuels. Biocapacity, referred to as the new wealth of nations (Ewing and Moore, 2010), is the ability of ecosystems to provide the resources people need and absorb the wastes they create. At 58.2 million global hectares (gha), New Zealand has the world's largest biocapacity, and uses only 39.4% of it. With an ecological footprint of 22.9 million gha (Ewing and Moore, 2010), New Zealand is also unhappily responsible for one of the world's larger ecological footprints of 5.17 gha per person (shown in figure 1). As shown in figure 1 the global 'fair share' footprint, which all people could have without overtaxing resources, is 1.7 gha per person as opposed to the average of 2.7 the world is using currently, made possible by using finite resources such as coal, oil and uranium (WWF, 2010). Should India, whose biocapacity is 630 million gha and whose ecological footprint is only 0.9 gha per person, (Global Footprint Atlas 2014) be following the example of countries like New Zealand, which take far more than their fair share of the Earth's resources?

This study is a comparison of current sustainable design practice in India and the developed world to identify if, and how, India might learn from the successes and failures of 'developed' countries. The aim is not only to determine how varying nations identify and assess sustainable design but also whether there has been a shift in focus in sustainable developments. The best example of a sustainable development in India (Govardhan Eco Village) will be compared with similar privately funded examples from New Zealand (Earthsong), Germany (Solarsiedlung), the United Kingdom (BedZED), Japan (Fuji Eco-park Village), and Australia (Crystal Waters), countries which have roughly similar ecological footprints, all well above the fair share (Figure 1).

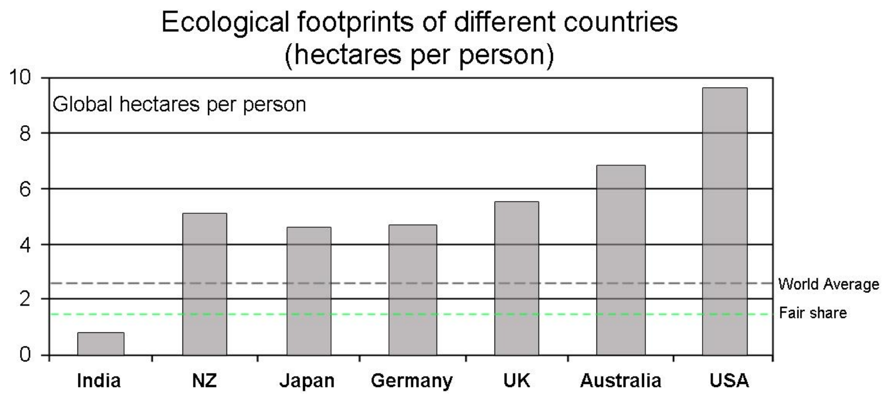

Figure 1 Case study selection based on footprint (USA included for comparison only). Source: Global footprint network (2010)

The developments were selected based on self-reported claims of sustainability that purport to follow guidelines determined by Agenda 21 (United Nations Environment Programme, 1992) as discussed by Bell and Morse (2008) and by Bakshi (2009).

CASE STUDIES

Table 1 identifies the self-reported case study parameters ordered by their occurrence in the six developments to give an overview of the sustainable design emphasis in each case.

Table 1: Parameters in occurrence order

	New Zealand	Germany	Australia	Japan	UK	India
	Earthsong	**Solarsiedlung**	**Crystal Waters**	**Fuji Eco-Park**	**BedZED**	**Govardhan**
Waste water recycling.	✓	✓	✓	✓	✓	✓
Renewable source of energy	✓	✓	✓	✓	✓	✓
Low energy lighting	✓	✓	✓	✓	✓	
Passive solar design	✓	✓	✓	✓	✓	
Efficient recycling and segregation	✓	✓	✓	✓		✓
Rain water collection	✓	✓	✓	✓		
Local work availability	✓	✓	✓			✓
Proximity to public transport	✓	✓		✓		✓
Environmentally friendly materials	✓		✓			✓
Energy efficient appliances		✓		✓	✓	
On site sewage treatment	✓				✓	✓
Farming			✓	✓		✓
Permaculture design	✓		✓	✓		
Facilitates changing demographic	✓	✓				
CHP system		✓			✓	
Sustainable behaviour education				✓		✓
Self sustained food sources				✓		✓
Preserving local ecosystems				✓		✓
Energy Plus design		✓				
Balance of hydrology			✓			
Site restoration/reforestation			✓			

Case study one: Earthsong Eco-Neighborhood, New Zealand (2008)

Earthsong is based on the three principal areas of sustainable design (Environmental, Social and Economic) as established in ‘Agenda 21’, (Bell and Morse, 2008). Environmental consideration at Earthsong relates to the overall design of buildings and landscape into a coherent whole; orientation of all buildings on principles of passive solar design and natural climate control; building materials choice considering embodied energy, durability, toxicity, recyclability and environmental impact; collection and re-use of rainwater and waste water; renewable energy; solar hot water systems; and clustering of buildings creating productive open spaces (Earthsong 2014). The ‘village’ arrangement balances the needs of individuals and community. Physical spaces encourage a diverse range of social interaction; cars are confined to the outer regions of the site; varying dwelling sizes support a wide range of ages and household types; a centrally located common house is a focus for community activities; and resident management occurs through the body-corporate. A self-sustaining economy to allow creation of on-site work and wealth was achieved through shared workshop and office facilities; leasable multi-purpose workspaces (stage 2); reduced domestic energy costs from energy efficient and passive solar design; reduced commuting costs through the site being 500 metres from a railway station.

The Earthsong Eco-Neighborhood’s incorporation of some onsite renewable energy and permaculture makes it a more sustainable co-housing project. Sustainable materials were also considered important, with careful management of non-renewable resources. As stated (Earthsong Eco-neighbourhood 1999) this required;

- Specifying sustainably grown timbers as an integral part of each building;
- Using coating systems/carpets/thermal insulation with reduced environmental impact;
- Incorporating some major recycled building products.
- Encouraging better management of water as a precious resource through rainwater harvesting and having water efficient devices and grey-water recycling.

Case study two: Solarsiedlung (The Solar Village), Germany (2008)

Solarsiedlung GmbH is a sustainable scheme that incorporates ‘energy-plus’ initiatives to produce more energy than it consumes (EEG, as of 1st April 2000). Apart from terraced housing it has an office/housing block based on German Passivhaus and Plus Energy House directives. Environmental consideration comes from material selection, appliance choice, energy plus initiatives and limiting cars to the outskirts of the site. The scheme has four main elements (Behling & Schindler 1996);

1. Use of environmentally friendly materials (wood from regional forests, PVC-free, environmentally friendly insulation)
2. Highly insulated thermal building shell (heat requirement: 11-14 kWh/m² per year)
3. Active ventilation with heat recovery
4. Photovoltaic panels on the roofs

The distance between buildings allows passive solar heating and solar electricity generation. Solar electricity is fed into the grid and extracted as needed. Any additional energy required in the winter is provided by a local wood-chip fuelled combined heat and power station (Solar Architecture 2014). Rainwater passes through a "biotope" for purification and to relieve pressure on local storm water drains, with the aim of recharging the city groundwater. Some rainwater is captured for garden irrigation and toilet flushing. The buildings have large south-facing glazed openings to maximize solar gain and small openings to the north to minimize heat loss. Vacuum insulation is used on opaque portions of the facade. Triple glazing reduces heat loss through windows and glazed facades (Behling & Schindler 1996). Because this project produces more energy (from renewable sources) than it consumes it can be considered to be sustainable design.

Case study three: Crystal Waters Eco-village, Australia (1988)

In 1996, Crystal Waters in Australia received a United Nations World Habitat Award for its "pioneering work in demonstrating new ways of low impact, sustainable living" (Barton 2013). There were six design objectives at Crystal Waters:

1. Clean air, water and soil (thus food)
2. Freedom in spiritual belief
3. To work towards a guarantee of meaningful activity for all
4. To create a place for healthy play and safe recreation
5. Active social interaction
6. Healthy shelter

Crystal Waters accommodates up to 300 people with 80% of the land set aside for agriculture, and steeper areas given to forestry, recreation and natural habitat.The houses are built of a variety of materials such as straw bale, rammed earth, poles and mud domes, and avoid rainforest timbers and toxic chemicals. The EcoCentre (for education) has rammed earth walls, photovoltaic power, rainwater collection, and a biolytic waste system. The 83 residential lots are arranged in clusters to encourage interaction, co-operation and a sense of belonging. Scheme aspects show careful consideration for the environment, social needs and the economy. Food is grown onsite and most residents maintain home gardens and orchards. The scheme has 'home occupation' zoning, which creates business zones within the residential areas (Barton 2013). The permaculture design (Mollison and Slay 1994), which has a diversity of plants and wildlife uses knowledge of eco-systems to create a more sustainable way of life. The hydrological balance was maintained, ensuring the quality and quantity of the water downstream was not negatively affected by the development (Mollison and Slay 1994). Seventeen multi-purpose dams provide a flood mitigation strategy by absorbing runoff, with the overflow directed into the rivers via swales (Barton 2013). They are also a source of emergency water. A long term sustainable approach is taken to forestry. Trees were planted to provide habitat and moderate environmental extremes, as well as for various timber end uses. Buildings make extensive use of renewable materials with particular emphasis on passive solar design (Barton 2013).

Case study four: Fuji Eco-park village, Japan (2000)

Fuji Eco-park village is a project with a perfected "Permaculture Master Plan" (World Permaculture projects 2014). The project was scrutinized for its environmental and financial self-sufficiency; and its ability to be self-replicating and because it achieved all these it was included in a global list of sustainable permaculture projects (World Permaculture projects 2014). It was also recognized as an example of sustainable living in the Eco-village conference in Japan 2005 (GEN 2014). The Fuji Eco-park village is an eco-housing development with a single main dwelling, the Centre House, built on passive solar principles on 7.5 acres of land. Environmental consideration is given to transportation options, appliance choice, materials selection, energy consumption, and construction methods. The scheme has four main elements (Permaculture News 2014);

1. Renewable agriculture
2. Renewable energy
3. Sustainable design for the built environment
4. A water conservation scheme

The implementation of all four aspects makes this project unique. The layout is based on wind and solar orientation for renewable agriculture and renewable energy collection. There are solar PV panels and onsite wind generated electricity. The site layout has a main area for vegetables, an animal farm and a wind turbine farm. Because the scheme revolves around a single Centre House there was ample space for PV panels at ground level, making them easier to maintain. The wind farm and PV panels are said to produce more than enough energy for the single dwelling. To achieve renewable agriculture 90% of the land was devoted to food self-reliance (World Permaculture projects 2014). This led to the creation of a potato field, blueberry farm, pumpkin field, sweet corn field, herb gardens, earth worm farm, bee keeping farm, compost area and the orchard (Permaculture News 2014).

Case study five: BedZED (Beddington Zero Energy Development), United Kingdom (2002)

The BioRegional committee defines BedZED as the “UK’s largest mixed use sustainable community” (Bio-regional 2009). It further states the scheme is one of the most successful projects to follow Agenda 21 in the United Kingdom. The project was aimed to be a zero energy design, only relying on energy from onsite renewable sources (Desai and Riddlestone 2002), and was designed to incorporate techniques to utilize resources sustainably. The three main principals of design were (Desai and Riddlestone 2002);

1. Zero fossil energy
2. Maximise passive solar energy
3. A “pedestrian first” policy

After its evaluation by the BioRegional committee (BioRegional 2009), the scheme was shown to be as not as successful in performance as intended. BedZED is the only one of the six case studies for which there is a detailed record of performance in practice. Identified in the report by BioRegional (2009), BedZED’s design reduces space-heating requirements by 88%, one of the major design features that was intended to contribute to this is the multicolored wind funnels that provided passive ventilation (BioRegional 2009), but these had been rendered inoperative by rust a few years after the building opened (Vale 2014). Hot-water consumption was 57% less then the UK average; the electrical power used, at 3 kWh per person per day, was 25% less than the UK average; 11% of this was produced by solar panels; mains-water consumption was reduced by 50%; and the residents' car mileage is 65% less than the UK average. There are 777 m^2 of solar PV panels. Tree waste was to fuel the development's cogeneration CHP plant to provide district heating and electricity, although this system is currently not working and electricity comes from the grid (BioRegional 2009). All dwellings face south to take advantage of solar gain, incorporate triple glazing, and have high thermal insulation (Desai and Riddlestone 2002). Rain water is collected and reused. Appliances are water-efficient and use recycled water. Low-impact materials were specified and these come from renewable or recycled sources within 35 miles of the site, to minimize embodied energy. This scheme incorporates collection facilities to support recycling. To encourage eco-friendly transport, electric and liquefied-petroleum-gas cars have priority over petrol and diesel cars and there are parking spaces for charging electric cars (Desai and Riddlestone 2002). All these design considerations mean people living in BedZED have a reduced ecological footprint (identified by BioRegional as 4.7 gha compared to the UK average of 5.5 gha) and this makes the project somewhat more sustainable (BioRegional 2009). Another very important aspect of BedZED is the fact that it also strongly promotes behaviour and lifestyle changes such as joining the car club which reduces the carbon emissions of occupants' whole lifestyle by 50% (BioRegional 2009). Encouraging behavioural change through governance and estate management, make BedZED one of the earlier eco-villages that is beginning to identify the importance of behaviour. However, communal elements like the CHP plant and "Living Machine" system to treat waste water have failed whereas those at a household scale (PV, gardens, passive solar, water) have worked (BioRegional 2009).

Case study Six: Govardhan Eco Village, India (2003)

Govardhan Eco Village aims for "Simple living and High thinking", and demonstrates practical ways of achieving a sustainable lifestyle. The scheme revolves around 5 elements (Govardhan 2014);

1. Natural Buildings
2. Sewage Treatment
3. Organic Farming
4. Alternative energy from solar energy and biogass
5. Education for sustainable behaviour

Govardhan Eco Village is a farm community spread over 60 acres at Galtare, Wada, 110 km North of Mumbai that incorporates use of alternative energy, eco friendly construction, and sustainable living. Alternative energy sources such as biogas and PV panels reduce dependency on the national grid (GEV 2013). The green building scheme considers existing ecologies, ensuring the constructional choices do not impact the surrounding site negatively. This is achieved by having separate building and planting zones. Use of materials 90% sourced from within a 100 kilometre radius (GEV 2013b), coupled with zoned construction, hinder unsustainable behaviour by limiting material choices possible in the built architecture. There is also a waste management system, linked with biogas generation on site, and water harvesting (GEV 2013c). Finally organic farming is the sole source of food making this project, like Fuji Eco-park in Japan, self-sufficient in food. As shown in table 1, most if not all the parameters for Goverdhan Eco Village focus on the behaviour and impact of the occupants, with less reliance on innovative technologies for generating energy. Everything from choices made during construction to the way occupants eat and sources of food are governed by local resources.

FINDINGS

Table 2: Parameters based on Agenda 21 sustainability indicators in date order

		Australia	Japan	UK	India	New Zealand	Germany
		Crystal Waters	Fuji Eco-Park	BedZED	Govardhan	Earthsong	Solarsiedlung
		1988	2000	2002	2003	2008	2008
Technology	Renewable source of energy	✓	✓	✓	✓	✓	✓
	Low energy lighting	✓	✓	✓		✓	✓
	Passive solar design	✓	✓	✓		✓	✓
	Energy efficient appliances		✓	✓			✓
	Energy Plus design						✓
	CHP system			✓			✓
	Efficient recycling and segregation	✓	✓		✓	✓	✓
	Waste water recycling.	✓	✓	✓	✓	✓	✓
	Rain water collection	✓	✓			✓	✓
	Balance of hydrology	✓					
	Permaculture design	✓	✓			✓	
	Local work availability	✓			✓	✓	✓
	Proximity to public transport		✓		✓	✓	✓
	Facilitates changing demographic					✓	✓
	On site sewage treatment			✓	✓	✓	
	Environmentally friendly materials	✓			✓	✓	
	Preserving local ecosystems		✓		✓		
	Site restoration/reforestation	✓					
Behaviour	Farming	✓	✓		✓		
	Sustainable behaviour education		✓		✓		
	Self sustained food sources		✓		✓		

In Table 2 the order of the parameters has been changed to place those parameters that can be considered ‘technology based’ towards the top and those that can be considered ‘behaviour based’ towards the bottom. The trend line in table 2, which follows the mid-point of the parameters in each case study shows that no obvious change based trends in the parameters are observable over time. This suggests the focus on technology versus behaviour is arbitrary.

In the next step (Tables 3 and 4) the case studies were segregated and grouped. Grouping the ‘eastern’ case studies (Japan and India) seperately from the ‘western’ case studies (England, Germany, Australia and New Zealand) created two distinct trends, showing a definite shift in focus.

Table 3: Eastern Model

		Japan	India
		Fuji Eco-Park	**Govardhan**
Technology	Renewable source of energy	✓	✓
	Low energy lighting	✓	
	Passive solar design	✓	
	Energy efficient appliances	✓	
	Energy Plus design		
	CHP system		
	Efficient recycling and segregation	✓	✓
	Waste water recycling.	✓	✓
	Rain water collection	✓	
	Balance of hydrology		
	Permaculture design	✓	
	Local work availability		✓
	Proximity to public transport	✓	✓
	Facilitates changing demographic		
	On site sewage treatment		✓
	Environmentally friendly materials		✓
	Preserving local ecosystems	✓	✓
	Site restoration/reforestation		
	Farming	✓	✓
	Sustainable behaviour education	✓	✓
Behaviour	Self sustained food sources	✓	✓

Table 4: Western Model

		Australia	UK	New Zealand	Germany
		Crystal Waters	**BedZED**	**Earthsong**	**Solarsiedlung**
Technology	Renewable source of energy	✓	✓	✓	✓
	Low energy lighting	✓	✓	✓	✓
	Passive solar design	✓	✓	✓	✓
	Energy efficient appliances		✓		✓
	Energy Plus design				✓
	CHP system		✓		✓
	Efficient recycling and segregation	✓		✓	✓
	Waste water recycling.	✓	✓	✓	✓
	Rain water collection	✓		✓	✓
	Balance of hydrology	✓			
	Permaculture design	✓		✓	
	Local work availability	✓		✓	✓
	Proximity to public transport			✓	✓
	Facilitates changing demographic			✓	✓
	On site sewage treatment		✓	✓	
	Environmentally friendly materials	✓		✓	
	Preserving local ecosystems	✓			
	Site restoration/reforestation	✓			
	Farming	✓			
	Sustainable behaviour education	✓			
Behaviour	Self sustained food sources				

In Table 3, the Eastern Model, there is a shift over time towards incorporating more parameters for sustainable behaviour, education and food self-sufficiency. The Western Model (Table 4) shows an increasing reliance on technology. Crystal Waters is most similar to the eastern models and also one of the oldest western case studies (26 years old). Like the former it is self-sufficient in food but unlike the eastern case studies (and the other western ones) it does not have good access to public transport and other local facilities, suggesting sustainable settlement design in the west might only follow the eastern model if the site is rural and remote. This also suggests that the differences may be to do with having a suburban rather than a rural location. However, this would require further research and an extended list of case studies, as well as more detailed studies of measured performance. The trends depicted in the findings of this paper are established through a very small sample, especially for the eastern set. In addition, it would be worth carrying out much more detailed studies to see the measurable degree of sustainability offered by each settlement, perhaps using ecological footprint, as for BedZED, the only one of the six which is relatively fully documented or per capita energy consumption.

CONCLUSION

This research shows that most (if not all) the case studies appear to consider themselves in alignment with Agenda 21. However this ‘tick the boxes’ approach to assessment does not highlight a more fundamental difference in the approach to sustainable development as shown by the Eastern and Western Models. The former, with less reliance on technology and more on human capital, could be viewed as more sustainable than the Western Model. It has been shown by other research that significantly greater reductions in ecological footprint and therefore increased sustainability can be achieved by behavioural change than by technology (Vale and Vale, 2013). Further detailed investigation of ecological footprint and other measured aspects of performance in use, such as per capita energy demand, would show if this is indeed the case.

Given the state of the world, it is perhaps the case study from India that is showing the way to true sustainable development, especially for developing countries, with the focus on sustainable education, behaviour and food self-sufficiency. As BedZED shows, reliance on 'innovative' technology can be misplaced, whereas where the community is responsible for its own food and dealing with its own wastes, based on human capital, there is less chance of failure.

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Spatial Structure of City Blocks with Vacant Lands in Edo, Early Modern Tokyo - Introducing the Appropriate Wind into Outdoor Living Spaces –

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ABSTRACT

One of the main factors of urban heat island phenomena is surface temperature, and surface temperature is mainly affected by spatial geometry and material of cities. The townsmen's areas in the city of Edo, early modern Tokyo, were totally different from the present day metropolis in these factors. A series of papers evaluated the summer thermal environment of these townsmen areas using numerical simulation, in order to acquire knowledge for designing an environmentally symbiotic city in Asia. In the previous paper, summer surface temperature and sensible heat flux from surface in a typical Machiyashiki (= city block) was evaluated using numerical simulation. The following result was obtained; the nighttime heat flux was negative, indicating that the townsmen residential areas in Edo were never subject to the nighttime heat island phenomenon. Although the residential areas were notorious for their densely populated and low-rise wooden buildings, some vacant lands were scattered in Machiyashiki temporally, according to historical materials. In this paper, summer thermal and wind environment in several city blocks with vacant lands, located next to the previous target site, was calculated using coupled analysis of heat balance and airflow, concerning the influence of south wind from the bay. The result showed that, in outdoor living spaces, people could attain moderate wind, which was blowing down to the south-north alley through vacant lands and gardens, in the evening. From this, it was confirmed that some vacant lands and spatial structure of Machiyashiki in Edo made it possible to introduce the appropriate wind into outdoor living spaces under the comfort thermal radiant environment on a specified time section. The daily changes of sensible heat flux from surface in several city blocks were also calculated, and the result showed that these vacant lands had effect on reducing daytime heat island phenomena.

1. INTRODUCTION

The urban heat island phenomenon has become a serious modern-day problem. Surface temperature is one of the main factors that determine this phenomenon, and mainly affected by spatial geometry and building materials used in urban areas. The city of *Edo* was a metropolis that existed from the 1790s to the 1860s, after which it was renamed as Tokyo. The urban residential areas in *Edo* differed greatly from those in present-day Tokyo in terms of their spatial geometry and building materials. The objective of this study was to acquire a fundamental understanding of how to design a better summer thermal environment based on the Edo townsmen areas for an environmentally symbiotic city in Asia.

In previous studies [1], [2], the summer surface temperature of *Machiyashiki* (city block) in *Edo*

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townsmen residential areas was calculated by numerical simulation [3] using the information gleaned from literature and historical materials of that time. The following result was obtained; the nighttime heat flux load was lower, indicating that the townsmen residential areas in Edo were never subject to the heat island phenomenon. Although the Edo townsmen residential areas were notorious for their densely populated and low-rise wooden buildings, some vacant lands were scattered in *Machiyashiki* temporally because of frequent fires, according to historical materials (Fig. 1). In addition to the constant south wind from the bay, these vacant lands might have affected the thermal and wind environment of outdoor living spaces in these city blocks. In this study, the summer thermal and wind environment in several *Machiyashiki* was calculated using the coupled analysis of heat balance and airflow. The influence of vacant land in city blocks was also evaluated.

Figure 1. Spatial composition of the Target Area and Major Outdoor Living Area

2. SELECTING MODELS AND ARRANGING INFORMATION FOR SIMULATION

2-1. Selecting Simulation Models

To reproduce the thermal and wind environment in outdoor living areas, the reproduction model calculated three components: the distribution of (1) wind velocity, (2) surface temperature, and (3) air temperature. For complicated spatial structures in *Machiyashiki*, the coupled analysis of heat balance and airflow, proposed by Hoyano (2007) [4], was suited for this study. This analysis consisted of two simulation models: a 3D-CAD-based thermal simulation tool [3] and generalized CFD software (STREAM). The 3D-CAD-based thermal simulation tool could calculate the detailed distribution of the surface temperature in consideration of the airflow distribution. The turbulence model used in the generalized CFD software carried out a steady-state analysis in a high Re k- ε turbulence model, which had enough precision on account of the average airflow in *Edo Machiyashiki*. In this method, the output condition of one simulation model is made the input condition of the other model until the calculation converges with sufficient precision.

2-2. Arranging Information for the Coupled Analysis

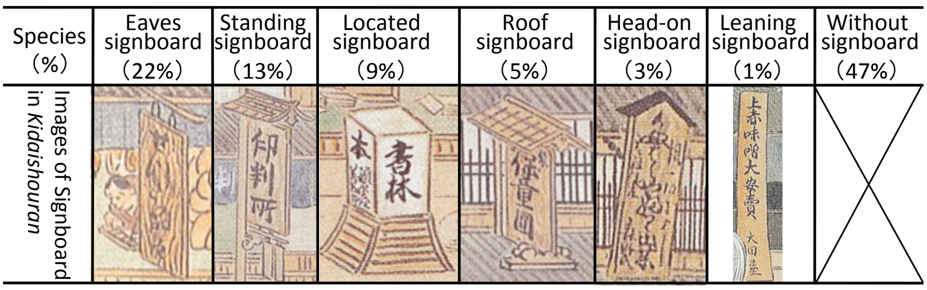
According to the proposed method [4], the necessary and sufficient information for the coupled analysis was arranged and the information was classified as known and unknown. The insufficient information for the coupled analysis, especially related to CFD, was identified (Table 1). In this section, this unknown information is presented as obtained from previous studies and historical materials.

Table 1. Necessary Information for the Coupled Analysis

	Classification			Known Information	Unknown Information
Buildings	Townhouse	Building	Spatial Form	Common (Site Plan, Measure), Plan (Placement, Room Layout), Elevation (Structure, Dimension of each member, Pitch: Roof)	Site Plan (in a Distorted Site), Plan (Selling Space)
			Material	Surface Material (Wall, Roof), Cross Section, Thermal Physical Properties	Surface Material & Cross Section (Selling Space)
		Belongings	Spatial Form	Measure, Form (Drying Area, Shop Curtains)	Measure, Form (Signboards)
			Material	Surface Material, Cross Section, Thermal Physical Properties (Drying Area, Shop Curtains)	Surface Material, Cross Section, Thermal Physical Properties (Signboard)
		Garden	Spatial Form	Plan, Measure, Form	Placement of Greens
			Material	Surface Material, Cross Section, Thermal Physical Properties	Surface Material, Cross Section (Greens)
		about CFD		–	Pressure Loss Boundary (Shop Curtains)
Common Facilities	Common Toilet, Common Well, Dustbin	Building	Spatial Form	Common (Site Plan, Measure), Plan (Placement), Elevation (Structure, Pitch: Roof)	–
			Material	Surface Material, Cross Section, Thermal Physical Properties	–
		about CFD		–	–
Ground Surface	Sewage Gutter	Spatial Form		Plan (Placement)	–
		Material		Surface Material, Cross Section, Thermal Physical Properties	–
	Ground Surface	Spatial Form		Plan (Placement)	Plan (Placement)
		Material		Surface Material, Cross Section, Thermal Physical Properties (Streets, Alleys)	Surface Material, Cross Section, Thermal Physical Properties (Vacant lands)
Green	Tree & Suface	Species		–	Tree Specises
		Spatial form		–	Tree Hight, Crown Width, Trunk Heiight
		about CFD		–	Drag Coefficient of Tree, LAI, Green Coverage
Objects	Wooden Gate on the Streets	Spatial Form		–	Site Plan, Measure
		Material		–	Surface Material, Cross Section
		about CFD		–	Drag Coefficient of Lattice
	Wooden fence	Spatial Form		Site Plan, Measure	–
		Material		Surface Material, Cross Section	–

2-2-1. Signboards in the Streets

Ito (2003) [5] classified the placement and frequency of different objects in the arterial streets of the Edo townsmen area from the pictures in *Kidai-Shoran* [6]. Based on this study, the objects were classified into six groups from a total of 89 townhouses and three signboards were selected as having a high number. In this study, eaves, signboards, and standing signboards were selected as located signboards (Fig. 2). The size of the signboards was set as 1212 mm depending on *Edofunai-Ehonfuzokuourai* [7], which describes the life and customs of townsmen in Edo.



[Reference: Unknown , *Kidaishouran* , Berlin Orient art museum possession , 1804]

Figure 2. Objects in the Arterial Streets (e.g., Signboards)

2-2-2. Ground Covers in Vacant Lands

According to Ito (1986) [8], vacant lands in the city blocks were used as drying areas, scrapyards, or open space. In areas where it was hard to identify the things placed in the field, the use for vacant lands was classified as open space. Based on previous studies in weed science [9] and the summer weather on a particular day [1], it was determined that the vacant lands were covered in weeds. In this study, vacant lands were classified as open space with green fields.

2-2-3. Greens in the Townhouse Garden

Kaso-sho, which was a textbook on house physiognomy, was very popular in Japan at that time. In this study, the information contained in the textbook was used to identify the species and placement of greens in townhouse gardens [10]. The placement of greens was decided s follows: divide the garden into nine sections which was same way as at the time, and decide which greens are suitable for each section according to good and bad luck suggested in the kaso-sho (Fig. 3). The size of the greens was decided by depending on studies and documents obtained from the Japanese Institute of Landscape Architecture.

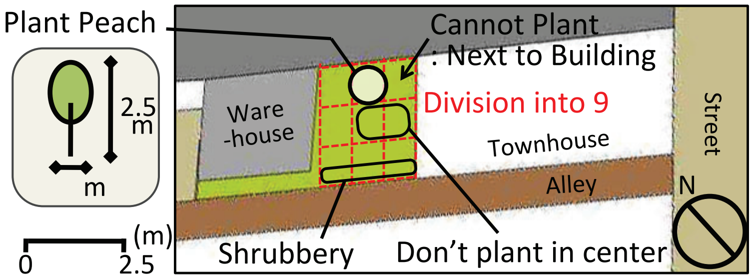


Figure 3. Placement of Greens in the Garden according to *Kaso-sho*

2-2-4. Residents' Summer Living Activities in Vacant Lands

For the evaluation of outdoor living areas, the summer living activities on vacant lands during each time section at that time were identified from previous studies and historical materials. According to Ito (1986) [8], vacant lands in the *Edo* townsmen area were used as drying areas during the day and used to enjoy the evening breeze during the evening. In *Edofunai-Ehonfuzokuourai* [7], there was a description about vacant lands which stated that, "many vendors and food stalls had been opened up from evening till night, and all the people live in *Machiyashiki* got together to enjoy cool evening breeze." From this information, the vacant lands in the target site could be set as outdoor living areas that some residents occupied during the morning, and all residents occupied to enjoy cool breeze during the evening. The identified information was added into the table of outdoor living space of residents, proposed in the previous study [2] (Table 2).

Table 2. Outdoor Living Space of Residents (Including Vacant Land)

	Living Areas	Dawn 6 4:40 ～	Morning 5 7:00 ～	Morning 4 9:20 ～	Noon 9 11:40 ～	Noon 8 14:00 ～	Noon 7 16:20 ～	Evening 6 18:40 ～	Night 5～ 20:20 ～
Inside *Machiyashiki*	Indoors (townhouse & Longhouse)	A, B, C, D, E	A, B, D	A, B, D	A, B, D, E	A, B, D, E	A, B, C, D, E	B, E	A, B, C, D, E
	Alleys	C, D, E	E	E	—	—	C, D, E ※2)	—	—
	Communal Areas ※1)	A, B, C, D, E	E	E	—	—	B, E	—	—
	Vacant Lands	E	E	E	—	—	A, B, C, D, E ※2)	A, B, C, D, E ※2)	
around *Machiyashiki*	Streets	—	—	—	—	—	A, B, C, D, E ※2)	A, B, C, D, E ※2)	—
	Outside *Machiyashiki*	A, C, D	B, C, D, E	B, C, D, E	C	C	A, B, C, D, E	A, B, C, D, E	—

Resident's Class: A)Merchant, B)Merchant's wife, C)Craftsman, D)Manual Laborer, E)Craftsman's wife
※1) spaces around common well, ※2)spaces around outdoor benches, — : vacant

3. PRECISION OF REPRODUCTION MODELS AND BOUNDARY CONDITIONS

3-1. Concerning Precision of Reproduction Models

Considering the width of streets and the lengths of the members of buildings, which were different depending on the type of outdoor living spaces, the precision of the reproduction model was set. The buildings in the city of Edo were measured using the Japanese measuring system. The simulations in this study were calculated in a structured grid. As a result, the minimum width of each mesh in CFD was 300 mm for streets and 100 mm for alleys. Finally, a model of the target site was created for this simulation (Fig. 4).

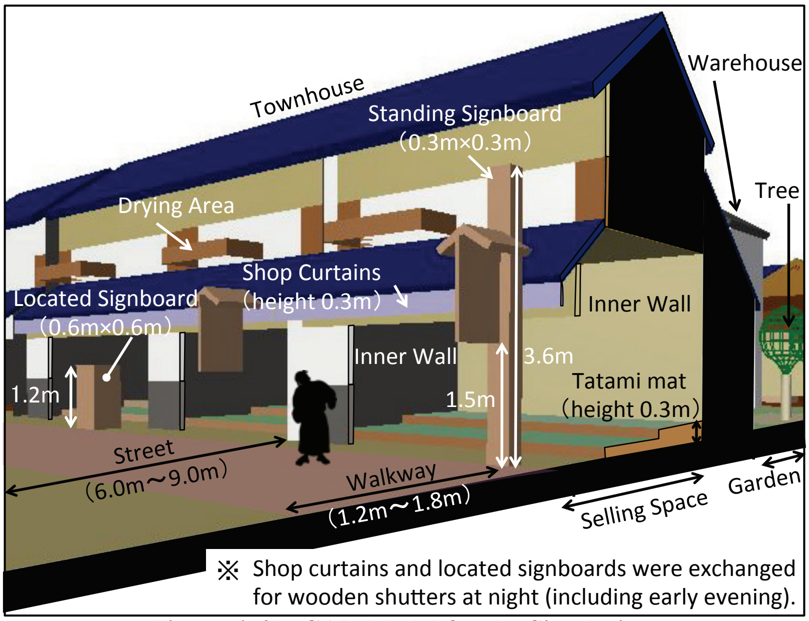


Figure 4. 3D-CAD Model for the Simulation

3-2. Setting Boundary Conditions on Building Parts

The coupled analysis needed to calculate not only values of thermal physical properties but also boundary conditions of building members. Although the thermal physical properties of building members had been prepared in the previous study [1], boundary conditions of building members had to be considered. As the predominant wind direction in the streets was arranged vertically with respect to the wooden lattice gate, the gate served as a substitute for a grid-like panel in CFD, and the pressure loss boundary of the gate was determined depending on the architectural design data corpus [11]. The parameters (coefficient, LAE, green coverage ratio) necessary for calculating the effect of trees in CFD were set depending on Yamada (1982) [12].

4. EVALUATING THE INFLUENCE OF VACANT LANDS ON THERMAL AND WIND ENVIRONMENT IN *EDO MACHIYASHIKI*

In this chapter, the distribution of surface temperature, wind velocity, and air temperature of the target site was calculated on a clear summer day [1] using the coupled analysis [4], and the influence of vacant lands in Machiyashiki on the outdoor thermal and wind environment was evaluated.

4-1. Calculation of Surface Temperature, Air Temperature, and Wind Velocity

The surface temperature at the target site on a clear summer day was calculated using the 3D-CAD-based thermal simulation tool [3]. The room and air temperatures were maintained at the same value because the buildings at that time were not airtight. Depending on the average vertical thermal distribution calculated previously, the ground temperature at time 0:00 was set as the underground thermal boundary condition. The simulation was calculated over five days and was run for the first 4 days under the conditions mentioned above. The distribution of surface temperature on the fifth day was regarded as the periodical steady state adapted to CFD as input data in the coupled analysis.

Airflow was calculated using generalized CFD software (STREAM). The nested grid method was adapted to the airflow analysis to incorporate the influence of surroundings. Table 2 lists the boundary conditions used in this calculation. First, in the wide area, only the airflow analysis was adopted with a minimum mesh size of 900 mm. The wind velocity and direction were considered as boundary conditions (inflow and outflow) for the middle area. Next, in the middle area, the coupled analysis was adopted with a minimum mesh size of 300 mm. The air temperature, wind velocity, and wind direction were considered as boundary conditions for the middle area. Finally, in the narrow area, coupled analysis was adopted with a minimum mesh size of 100 mm. The boundary conditions were the same as those for the middle area (Fig. 5).

Table 2. Boundary Conditions of the Coupled Analysis

Analysis range	Wide area	Middle area	Narrow area
	1080m × 1080 m × 54 m	230.4m × 256.5 m × 45 m	Different in each
Number of Mesh	1200 (x) × 1200(y) × 60 (z)	768 (x) × 855(y) × 140 (z)	–
Mesh Size (min)	900mm	300mm	100mm
Turbulant model	Standard k-ε Model		
Algorithm	SIMPLE, Regular method		
Different Scheme	QUICK		
Inflow boundary	Wind direction: South		Fiigures are nested from the analyses in Middle area and Narrow Area
	Wind Speed: 6.1 m/s (Standard height 15m)		
	Exponent: 0.2		
	$k=2.149m^2/s^2$, ε =0.073m2/s3		
Outflow boundary	Surface Pressure: 0 Pa		
Sky, Side boundary	free-slip		
Solid surface	no-slip		
Surface Temperature	Calculated figures by 3D-CAD based thermal simulation tool		

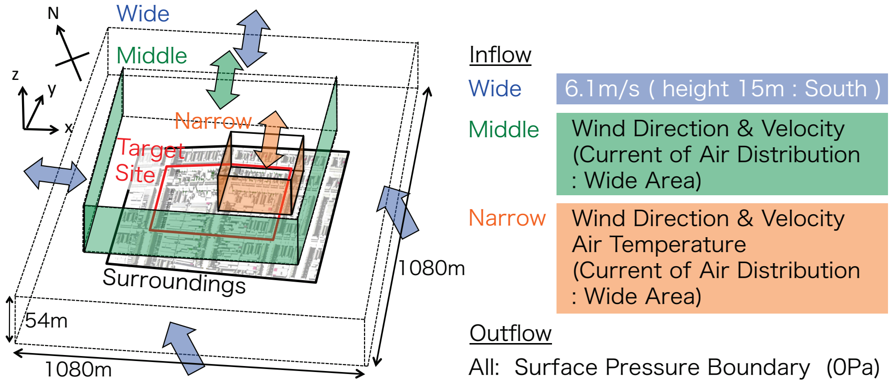


Figure 5. Analysis Range (Wide, Middle, Narrow)

4-2. Surface Temperature and Heat Flux from Target Site

Both during the day and at night, the surface temperature of the roof in long houses (Japanese cedar) and townhouses (clay tile roofing) had the same tendency as was found in the previous study [1]. Because of the low thermal conductivity and thermal capacity, the surface temperature of Japanese cedar and clay tile roofing was more than 55°C (up to 65°C) during the day and 1–3°C lower than the air temperature at night. The surface temperatures of vacant lands fell from 35°C to 25°C at night. Although there were trees inside Machiyashiki, the trees had little effect on creating shade because of their size.

The sensible heat flux from each of the 17 *Machiyashikis* in the target site was evaluated from the heat island potential (HIP) [13], an index that indicates the amount of heat transferred to the surrounding air from an area on a typical day in terms of the heat island phenomenon (fine weather and low wind speeds). Note that all the vertical unevenness of the surfaces is also regarded to be part of the horizontal surface area. The index was calculated using the equation below (Eq. (1)).

$$\mathrm{HIP}=\frac{\int_{\text{all surfaces}}(T_s-T_a)\,ds}{A} \quad \text{... (1)}$$

Ts: surface temperature of a minute plane inside the area of interest (ºC),
Ta: air temperature in the area for interest (ºC),
A: horizontal projected area of the target site (m^2),
ds: area of a minute plane (m^2)

The difference in the spatial structure of each *Machiyashiki* was considered from the daily change in the HIP (Fig. 6). The sensible heat flux from all *Machiyashikis* were extremely high during the day and low at night, which means that most of the solar radiation at the target site was immediately radiated back toward the surrounding air. Therefore, during the summer, the heat island phenomenon never developed in the city blocks of *Edo* at night with or without vacant lands. However, the daytime HIP of *Machiyashiki* with vacant lands was getting lower in inversely proportional amounts to the area of vacant land during the day (5–15°C lower than usual one).

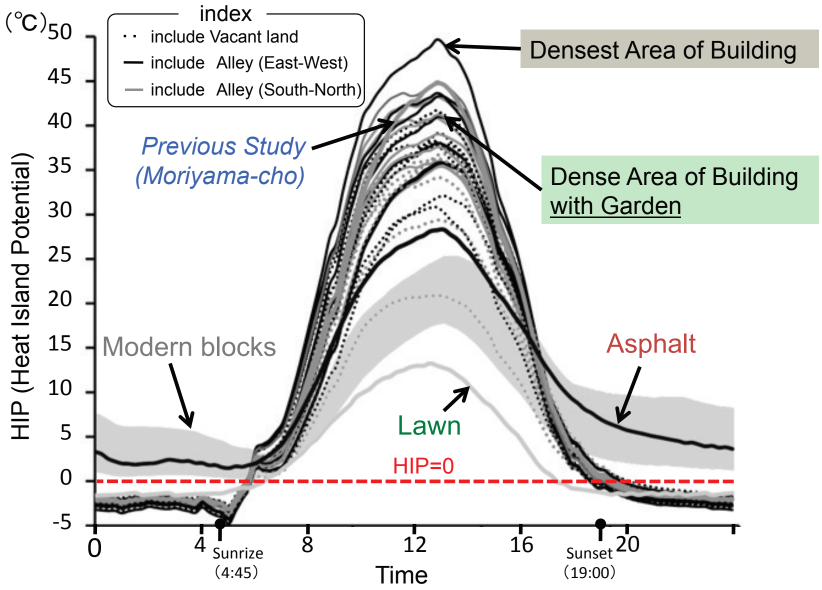


Figure 6. Daily Change of HIP in each *Machiyashiki*

4-3. Thermal and Wind Environment in Outdoor Living Areas

At Noon 7 (during 16:20 to 18:39), which was Japanese local time section in 19th century, most of the residents in *Edo Machiyashiki* stayed in the streets and alleys to enjoy the evening breeze (Table 2). The influence of vacant lands on the thermal and wind environment in the residents' living areas was evaluated during this period.

4-3-1. Street (east-west)

The distribution of mean radiant temperature (MRT) at the living height (1.5 m) in the vacant areas facing the east-west street was lower than the air temperature because the surface temperatures were the same as the air temperature and the area was open to the sky and was able to get nocturnal radiation cooling. Whereas wind blew into the street from the vacant land at 2.5 m/s, the air temperature, owing to heat from nearby building roofs, was 30.5°C, which was 0.5°C higher than the wind temperature (Fig. 7a). In this case, the spatial structure of *Edo Machiyashiki* had a negative effect on the thermal and wind environment, and it was difficult for the residents to enjoy cool air in the evening.

4-3-2. Street (north-south) Facing Large Vacant Lands

As the wooden gate reduced the wind velocity, the wind in the large area of vacant land facing the north–south street was getting mild (1.5–2.0 m/s). The distribution of MRT at the living height (1.5 m) in the vacant area was 0.5°C lower than the wind temperature (about 29.5°C). The air temperature at the same height was also the same as the wind temperature (Fig. 7b). Concerning the living activities during this period of time [2], it is considered a possible reason for the ability to enjoy the evening cool air in the vacant land.

4-3-3. Alley (north-south) inside Machiyashiki

Considering heat balance and airflow, the distribution of MRT was 27–28°C and was 2°C lower than the wind temperature because of the spatial structure of the north-south alleys and thermal capacity of building members, as was the result in the previous studies [1] [2]. Although it was expected that there would be little wind in the north-south alley with a dead end, wind collided with the roof of a townhouse and down flow flew into the alley at about 2.0 m/s next to the common area (Fig. 7c). The air temperature in the alley with the down flow of air heated by the wooden roofs of townhouses is about 30°C, and a little higher than MRT. Consequently, the environment in the north-south alley with vacant lands, gardens or common areas in *Machiyashiki* is good both in terms of thermal and wind conditions, and it was suited for residents to enjoy the cool air in the evening.

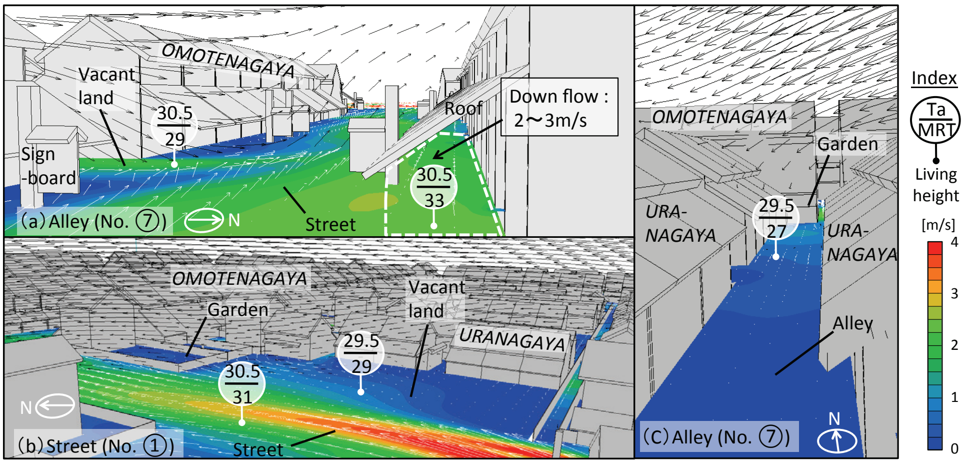


Figure 7. Distribution of Wind Direction and Velocity in the outdoor living spaces

5. CONCLUSION

In this study, the townsmen residential area of *Edo*, early modern Tokyo, in the 1790s to the 1860s was the focus, and the summer thermal and wind environment over several city blocks was calculated using the coupled analysis of heat balance and airflow. As a result, the influence of south wind from the *Edo* bay and vacant lands was evaluated and the influence of vacant lands in the townsmen residential areas were determined quantitatively. One influence is that townsmen residential areas in *Edo* with vacant lands had never become susceptible to hot summer nights because the spatial structure, vacant lands, and gardens in *Edo Machiyashiki* contribute to reducing HIP during the day as well. The other influence is that it is clear that some vacant lands works well with the spatial structure of *Machiyashiki* to introduce the appropriate wind into outdoor living spaces under the better thermal environment during a specified period of time, and this seemed to work well with the residents' living activities at that time. One of the future subjects is the analysis of the indoor thermal and wind environment.

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Optimization for Passive Design of Large Scale Housing Projects for Energy and Thermal Comfort in a Hot and Humid Climate

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ABSTRACT

Rapid urbanization in emerging economies, like Vietnam, is commonly realized via the multiplication of stereotype projects consisting of high-rise apartment blocks, terraced, semi-detached and detached houses. For these types of dwellings, in the hot and humid Vietnamese climate, individual air conditioning systems are typically used. This requires a large share of the country energy resources. Until recently comfortable traditional housing has however been built without using such energy intensive cooling. This paper focuses on the energy consumption and thermal comfort in residential buildings if only natural ventilation is used, taking into account the urban environment. Via a parametric simulation several building types are optimized, looking at the urban layout, building orientation and size, window design and internal wind permeability. A two-step procedure is followed for the analysis. Firstly, a simplified model is used to analyse a large range of design alternatives and secondly, dynamic energy and thermal comfort simulations with EnergyPlus are made for a selected number of design options. Results reveal that the average life cycle cost of the optimal cases is 34% lower than the reference cases. The window sizes, building layouts and urban forms are crucial parameters to compensate with orientations at the early design stages. One optimization procedure was developed to make maximum use of passive design measures in large scale housing projects.

Key words: EnergyPlus, GenOpt, Natural ventilation, Method for cost control, Parametric Wind pressure coefficient.

INTRODUCTION

Energy efficiency due to energy price and thermal comfort expectation in dwellings in urban areas lead to passive designs at the early stage. For passive design in hot and humid climates natural ventilation and thermal mass are crucial aspects. Natural ventilation, even when coupled with air conditioning, plays an important role when optimizing the life cycle cost and thermal comfort of buildings (A. T. Nguyen & Reiter, 2013). Studies in the context of Malaysia and Singapore proved that ventilation can provide good thermal comfort (Kubota, Chyee, & Ahmad, 2009). Moreover airflow through building openings is a critical factor influencing heat and moisture exchange between thermal

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zones and the outdoor environment (Hens, 2002). The wind pressure is therefore a boundary condition for airflow network models (Cóstola, Blocken, & Hensen, 2009).

Until recently vernacular housing has been built without using energy intensive cooling. In Vietnam, vernacular dwellings cannot provide perfect comfort, but they can be fairly well adapted to the local climate by using low energy design principles (A.-T. Nguyen, Tran, Tran, & Reiter, 2011). Therefore, buildings would benefit from low-energy mechanical systems and occupants' adaptive responses such as changing clothing, opening windows and switch on mechanical ventilation. In urban areas with high building density, such as in the Mekong Delta, cooling systems have however been increasingly installed in bedrooms. This is a consequence of inappropriate design of buildings and urban layouts, such as building orientation and density, window sizes and overhang depths. Those cooling systems require a large share of the country energy resources.

There exist however only a few studies to optimize both building geometry and urban layout by parametric simulation and which consider effects of natural ventilation and solar radiation on energy cost, thermal comfort and human responses. The aim of this research project is to predict building energy consumption and discomfort, in an urban context, if only natural ventilation is used and supplemented, if necessary, by cooling. Via a parametric simulation building types are optimized, looking at the urban layout, building orientation and size, window design and internal wind permeability. A two-step procedure is followed for the analysis. Firstly, a simplified model is used to analyse the effect of urban layouts by comparing six reference cases and optimising building geometry. Secondly, the parameters, defined on the neighbourhood and building scale are considered together. EnergyPlus is used for the dynamic energy calculations and GenOpt is used to search for an optimum out of the multiple design options.

METHODOLOGY

This study includes five steps. (1) Urban layouts, consisting of a number of terraced houses, are simplified and key parameters are selected. (2) For one reference terraced house, the wind pressure coefficients (Cp) on the roof and facades are estimated for 36 orientations and different urban parameters. (3) The Fanger model for thermal comfort evaluation is implemented. (4) A stepwise strategy to strive for occupant comfort is defined, including the following measures: adapt clothing - manage natural ventilation - switch on forced air circulation - start the cooling system. (5) An optimization method and an objective function are used to calculate the energy cost, investment cost and 60-year life cycle cost of the analysed options. All design parameters related to both the building and urban scale are varied and sent to EnegyPlus by the optimization tool GenOpt.

Simplifying urban forms and parameters selection

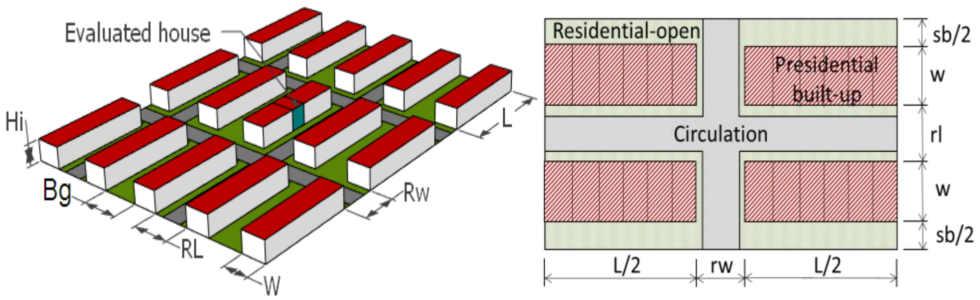

Figure 1 simplified urban fragment, representative for large scale housing projects in Vietnam.

The simplified urban layout model, as shown in **Figure 1**, represents large scale housing projects, which can be found in many suburban areas in Vietnam. The terraced house type was selected because this type constitutes the majority of the dwelling units in housing projects. This urban layout is described with following key parameters: the height of the surrounding buildings, road width, building setback and house width and depth. For this simplified urban fragment, the percentages of circulation, residential-open and residential-built-up are calculated, using the element method for cost control (De Troyer, 2008); (Allacker et al., 2011).

The terraced house geometry

As shown in **Figure 2,** a simple terraced house model was defined, including seven thermal zones: a stair case, a living room, a kitchen and four bedrooms. The outside doors are modelled as windows. The floor height is three meters and the depth of the circulation zone is four meters. A balcony, functioning as an overhang for shading, is provided along the whole house width. The geometric parameters of the analysed terraced house, which is representative for the Vietnamese city of Cantho, are shown in Table 1. This housing unit is simulated with different construction elements including external walls, internal walls, glazing and roof elements.

Table 1 Numerical variables and their design options (continuous variables).

Design parameters	Abbreviation	Initial values	Range (m)	Step size (m)
Urban layout:				
Height of surrounding buildings	H_1 to H_{14}	9	1 to 36	3
Width of roads	Rw, Rl	12	12 to 24	4
Back garden depth	Bg	12	12 to 24	4
Terraced row depth	W	16	10 to 20	2
Terraced row length	L	40	40 to 120	10
Terraced house geometry:				
Terraced house width	Bw	6	5 to 10	1
Front façade overhang	ov1	1.5	0.5 to 2	0.5
Rear façade overhang	ov2	1.5	0.5 to 2	0.5
Window width	win1, win2, wwr	1.5	1 to 5	0.5

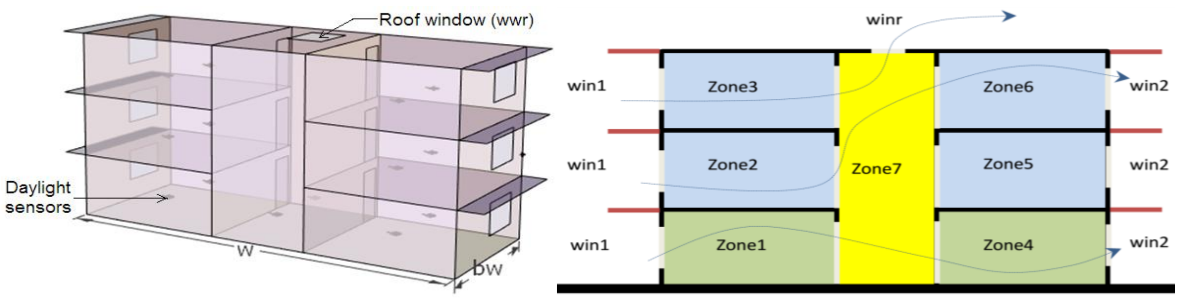

Figure 2 Terraced house section. Zone 1 and zone 4 are living room and kitchen. Zone 2, 3, 5 and 6 are bedrooms. Zone 7 includes the stair case and circulation area.

Wind pressure coefficient (Cp)

The TNO Cp-generator, developed in the Netherlands, is used to calculate the wind pressure coefficient (Cp) values on facades and roofs of block-shaped buildings. This generator is based on finite element calculations and has been verified with wind tunnel experiments (Nicolas Heijmans & Peter Wouters, 2003). The TNO Cp-generator was validated by measured data (B. Knoll, J.C. Phaff, & W.F. de Gids, 1995). This validation showed a rather good agreement between measured and calculated results. A similar approach, using this tool, was applied in other studies to obtain the Cp value for a large urban fragment (Sun et al., 2014).

Multiple linear regressions for wind pressure coefficient (Cp) values

For a specific wind orientation the Cp value in the middle of the windward façade of the terraced row, situated in the middle of the urban fragment, depends on 19 independent parameters. An overview of those parameters is given in **Table 1**: terraced row length (L), terraced row depth (w), width of road parallel with terraced row (Rw), width of road perpendicular to terraced row (Rl), building setback (Bg) and the height of the fourteen surrounding buildings (H_i) (with i = 1 to14, thus 5+14=19). The same dependency is true for the leeward façade and the roof. The theoretical combinations that can be derived by varying each parameter are very large. Therefore in a first step the "Latin Hypercube Sampling method" is applied to generate 200 combinations of 19 independent parameters. In a second step the Cp values of those combinations are calculated based on the TNO Cp-generator. In a third step, via multiple linear regression analysis, the coefficients of the equation, predicting the Cp values based on the neighbourhood parameters, are derived. For example, one regression function for the front façade is:

$$\mathbf{Cp_{front1} = a_{f1i}{*}Hi + a_{f2}{*}L + a_{f3}{*}W + a_{f4}{*}Rw + a_{f5}{*}Rl + a_{f6}{*}Bg + intercept.}$$

The model that has to be considered in order to obtain stable results consists of five building rows in depth direction, three buildings rows in width direction and an air volume height that is equal to 5 times the building height. In this study all 14 surrounding buildings were assumed to have the same height, but the model could also be used for buildings with different heights. In a next step, the same approach can be followed for another wind direction. In order to keep the model manageable only 36 orientations are considered, thus varying in steps of 10°. **Figure 3** compares the Cp values obtained from the TNO Cp-generator with those predicted by the linear regression function. The results of one geometric variant are shown for the front and back façade, and the roof, for the 36 wind directions. For all other variants a similar good fit could be found. As the "test reference year" (TRY) in EnergyPlus contains for each hour the wind speed and wind direction, linear approximations are used to derive the driving forces for natural ventilation. Based on opening characteristics and wind-permeability of the dwelling the inside air velocity is calculated. This air speed is then used for predicting thermal comfort based on the Fanger model.

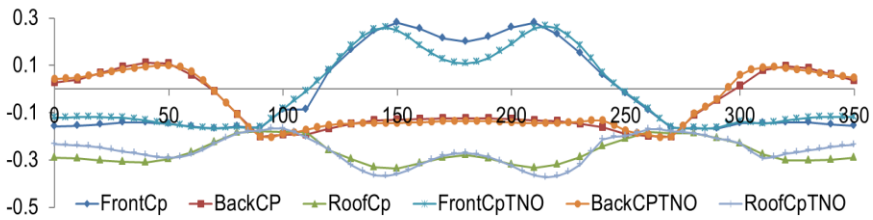

Figure 3 Wind pressure coefficient values of multiple linear regression functions (…Cp) and calculation with the by CpGenerator TNO (…CpTNO), (Nguyen Van, Miyamoto, Trigaux, & De Troyer, 2014).

Comfort evaluation and strategy based on dynamic schedules for ventilation and cooling

Fanger (Fanger, 1970) developed a thermal load index, consisting of a "predicted mean vote" (PMV) on a 7 points scale from "cold" (-3) over "neutral" (0) up to "hot" (+3), based on the heat balance between the body and the environment. His work was the basis for different thermal comfort standards, such as the ASHRAE Standard 55-92 (ASHRAE, 2004) and ISO 7730 (ISO 7730, 2005). In this method, the thermal comfort is defined as the condition when the PMV is between -0.5 and +0.5, which correspond with 90% of users satisfied. The PMV can be used to simulate control actions from "passive" to full HVAC (Fadzli Haniff, Selamat, Yusof, Buyamin, & Sham Ismail, 2013).

In this study, this approach was implemented in the following way: (1) The PMV values for a zero air velocity and minimum cloth-values (0.36), which are representative for the domestic habits in Vietnam, are calculated via the "Energy management System" in EnergyPlus. If the PMV value is higher than +0.5, fans are switched on. In the living areas, fans with three speed levels generate a wind speed of respectively 0.2, 0.4 and 0.6m/s. In the bedrooms, fans with two speed levels (0.2 and 0.4 m/s) are provided. When the maximal fan velocity is set and comfort is not yet reached, windows are closed and the cooling system is switched on with a set point of 27°C. During the simulations, activity levels of 1.2 met for the living room and 1.0 met for the bedrooms are considered. The living room, kitchen and staircase are assumed to be used from 5:00 to 9:00 and from 17:00 to 23:00 during working days. In the weekend, the living room is used from 5:00 to 23:00. The bedrooms are used from 23:00 to 5:00.

All lights in the model are controlled by time schedules and luminance levels using two sensors in each zone. The luminance levels for the living room, kitchen, bedrooms and circulation area are respectively 300 lx, 500 lx, 300 lx and 150 lx. 69 lm/W LED lights are considered in all zones. An example of input (occupancy schedule) and output (PMV, inside air velocity) is given in **Figure 4**.

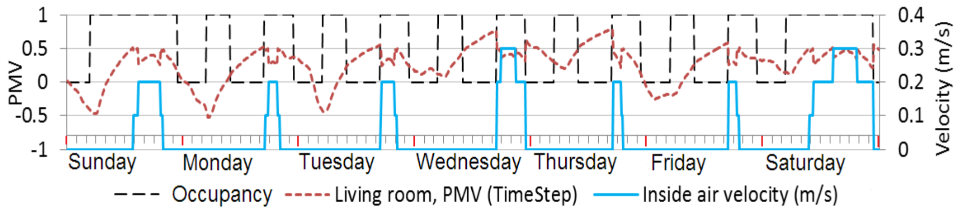

Figure 4 Example of a dynamic schedule for one week

Optimization method and objective function

To optimize the building costs with thermal comfort constraint, a parametric simulation, based on the dynamic energy simulation software, EnergyPlus 8.01, was used. Then EnergyPlus was coupled with the optimization tool GenOpt to minimize the results of the objective function (Wetter, 2011). The life cycle cost is present value which is calculated including construction, maintain, operation, land and infrastructure costs. The operation and maintain costs were estimated with 5% inflation rate and 10% nominal discount rate for the energy cost for 60 years life span. The unit costs were used from local data at Cantho and land cost based on (Nguyen Van & De Troyer, 2013).

The optimization of building design alternatives is a non-linear multi-objective process. Hence, it often requires a trade-off between conflicting design criteria, such as the initial construction cost and the operating cost (Wright, et al., 2002). The most common approach to optimize such conflicting criteria is to apply the concept of Pareto optimization in which a set of trade-off solutions, called Pareto front, is obtained. This approach results in many Pareto-optimal design options, out of which designers or users can select the most preferred one, based on their specific preferences. The study minimizes the sum of the initial cost and operational cost for energy, replacements and maintenance within the constraint that total discomfort hours should be smaller than 10% of the hours that people are present. The number of hours that cooling is required or that people feel dis-comfortable if no cooling is available and the required cooling energy based on a system with 100% efficiency is reported.

CASE STUDY

Varying all selected parameters with fixed north orientation

In **Figure 5,** as an example, input and output for one day in April are represented for one bedroom, in order to illustrate the variations in PMV values, operation of fans and cooling. Additional settings are: sleeping period from 23 to 5. As a rule, when the indoor air temperature is higher than the outdoor air temperature, the windows are opened for natural ventilation. As shown in **Figure 5**, the PMV values are between -0.5 and +0.5 during the occupation period from 0 to 5 am, thanks to the natural and forced ventilation. From 5 am nobody is present in the rooms and fans or air conditioners are stopped. At the same time, the increase in outdoor temperature results in a higher indoor air temperature and the PMV surpasses 0.5. From 17:00, the outdoor temperature is again below the indoor temperature, so that cooling via ventilation is possible. From 23:00 the bedroom is occupied and additional cooling is required during one hour.

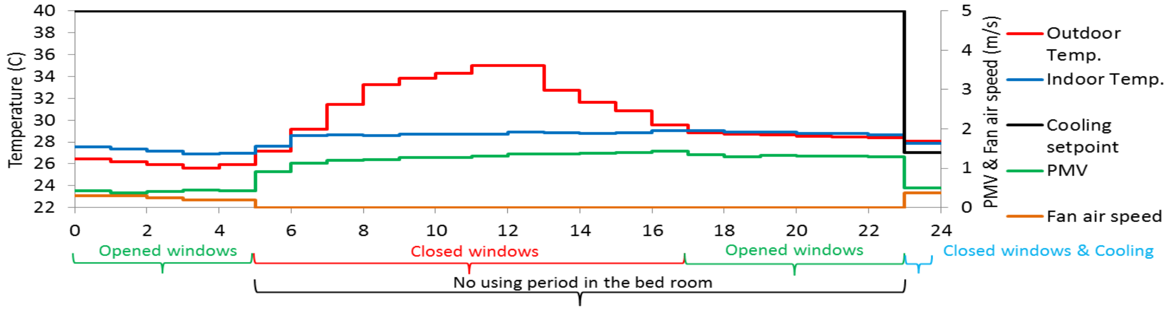

Figure 5 Ventilation volume, outdoor air temperature, zone air temperature, PMV values, zone air velocity and cooling set point, during one day in April, in zone 2 (bedroom).

The reference terraced house, using the initial values defined in Table 1, was analysed in six extreme urban layouts, considering north-oriented front façades, as shown in **Figure 6**. The results for the energy, construction and life cycle cost are reported for the reference cases and further optimised by changing window, glazing types and overhang sizes.

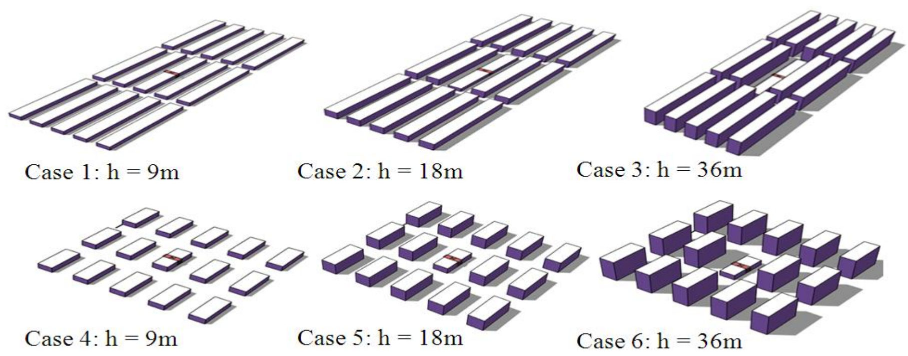

Figure 6 Six urban layouts with different built-up ratio and building densities:
Case 1, 2, 3: L =120m; W = 16m; Rl = Rw = Bg =12m; Built-up Ratio = 52%.
Case 4, 5, 6: L = 40m; W = 16m; Rl = Rw = Bg =24m; Built-up Ratio =25%.

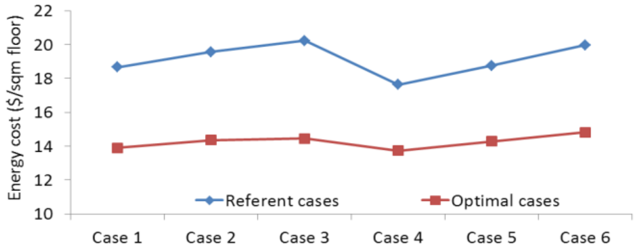

Figure 7 Energy cost of the reference terraced houses and the optimal solutions of 6 cases.

To evaluate the effects of solar radiation and natural ventilation, the 6 urban layouts, described in **Table 1** were analyzed by varying window sizes glazing types and overhang depths. The results show that the life cycle cost of the optimal cases is 34% lower than the reference cases, as shown in **Figure 7**. Moreover, we can see the impact of the urban layout on available solar radiation and natural ventilation: the models with a higher building density (narrow streets or higher buildings) require a higher energy cost for fans and cooling.

When only considering a fixed north orientation (A) for the front façade, as shown in **Figure 8** or varying all parameters including (B) orientation, as shown in **Figure 9**, the lowest building life cycle costs (including land and infrastructure costs) are respectively 245 and 242 ($/sqm floor) and energy costs are respectively 13.1 and 13.8 ($/sqm floor). As shown in **Table 2,** important differences are found for the optimal window dimensions, depending on the orientation. Moreover, the optimal height of surrounding buildings is 34.5 m for an orientation of 120 degrees, compared to 9.4 m for the north orientation because of the predominating south-east wind direction in summer time.

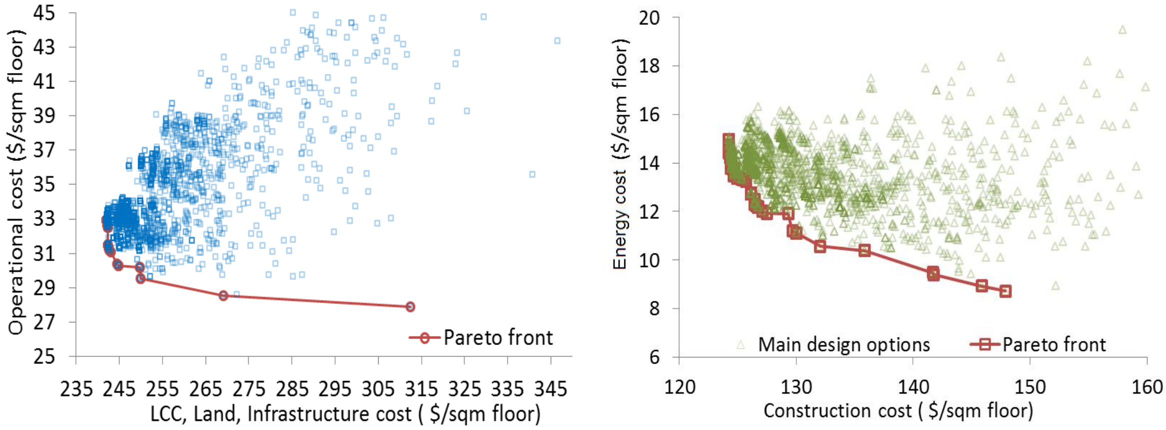

Figure 8 Pareto fronts of about 7300 design alternatives with north-oriented front façades.

Table 2 Optimization results for the neighbourhood model with north-oriented front façade (A) and varying orientation (B).

Case	L	W	Rw	Rl	Bg	H	Bw	ww1	ww2	wwr	ov1	ov2	orient
	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(degree)
(A)	120	20	12	12	6	**9.4**	10	**2.8**	**2.5**	0.97	0.5	0.5	0
(B)	120	20	12	12	6	**34.5**	10	**3.5**	**3.7**	1.09	0.5	0.5	120

Varying all selected parameters with orientation from 0 to 360 degree

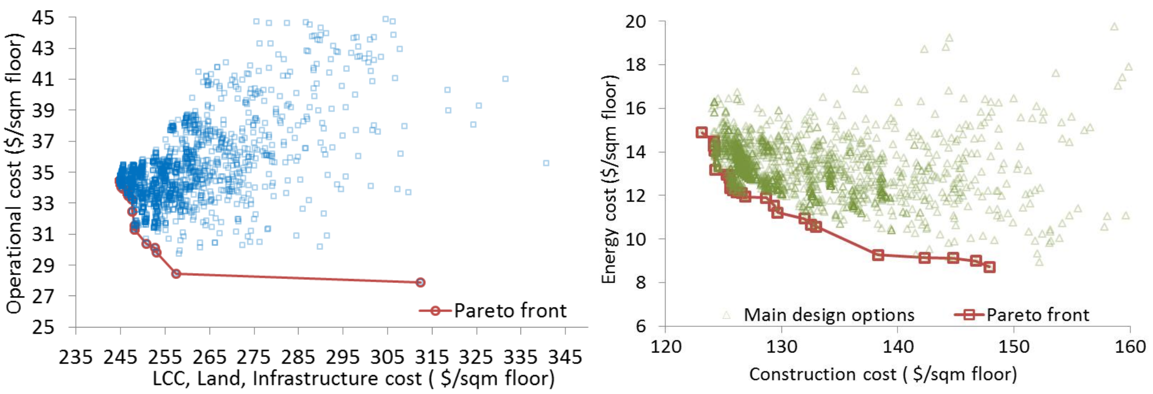

Figure 9 Pareto fronts of the neighbourhood model with varying orientation from 0 to 360.

Construction elements of optimal solutions of both cases with the North and 120 degree orientation are shown in **Table 3**. Pyrolytic clear glass is a reflective glazing type with low solar transmittance at normal incidence. This glazing type is appropriate to reduce heat gains in hot and humid climates with strong solar radiation.

Table 3 Optimization results for the construction elements

Elements	Material layers
Roof	6mm asphalt; 10cm reinforced concrete; 1.5 cm ceiling mortar
Internal wall	1.5cm mortar; 10cm clay brick; 1.5cm mortar
External wall	1.5cm mortar; 10cm clay brick; 1.5cm mortar
Glazing	6mm Pyrolytic clear glass
Floor	Floor tile; 1.5cm mortar; 10cm reinforced concrete; 1.5 cm ceiling mortar

DISCUSSION

The results of the optimization process show that adaptations on three levels should be considered in the early design stage: materials, building geometry and urban layout. First, reflective glazing can reduce solar gain. Moreover external walls with a clay brick layer and two layers of mortar provide a good thermal performance for a low cost. Second, when windows are protected from solar gains with overhangs, the window size should be maximized for improving natural ventilation. The cross ventilation can be increased because of the buoyancy wind flows street canyon (Allegrini, Dorer, & Carmeliet, 2014). Furthermore, road width, building setback and obstacle heights effect solar gains and wind circulation importantly. Hence, natural ventilation can be improved by window size, orientation and urban density. Not considered in this analysis is that trees and plants can reduce incident solar radiation, (Villalba, Pattini, & Córica, 2014), but also wind permeability. As a conclusion, the model can be adapted based on many design parameters at different scale levels. In reality, selecting a main orientation for an urban area depends on the existing infrastructure, but a disadvantaged orientation can be compensated by changing the building geometry.

CONCLUSIONS

In this paper one optimization procedure is developed to make maximum use of passive design measures in large scale housing projects, while guaranteeing a pre-defined thermal comfort. This procedure takes into account following aspects: solar radiation (including reflection), wind pressure coefficients for natural ventilation, building geometry, urban layout and a stepwise strategy adapting (1) clothing, (2) open or close windows, (3) vertical or ceiling fans, and (4) cooling. The implemented dynamic schedule provides comfort, in the hot and humid Vietnamese climate, during more than 90% of the occupation time. This strategy requires sustainable occupant behaviours or automatic control systems to follow the dynamic schedule or careful intervention by occupants. This model can be extended to other urban geometries, such as towers and urban street blocks, other energy management systems, other occupancy and activity schemes, other construction technologies and other economic scenarios (growth rate of costs, interest rates and life span.

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Investigations about a Scale of Correlation for the Relationship between Urban Physical Dimensions and Wind Cp

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ABSTRACT

This paper presents the results of an investigation focused on a scale for predicting the potential for naturally ventilate buildings in the urban environment. This scale is based on the Pearson r model of correlation coefficients between urban physical dimensions with the resulting wind-driven pressure coefficients (Cp). Numerical simulations using computational fluid dynamics (CFD) were performed to a large number of urban prototypes with simplified volumetric shape. These urban prototypes were originally based on ratios of actual urban areas. The systematic variation of the volumetric urban aspect ratio of these prototypes and the simulation for three wind directions allowed finding the relationship between the urban fabric and the ΔCp. The range in the urban prototype shapes covered as many types of urban fabric as possible, from high to low density, from low building centres to downtown skyscraper areas. Eventually, two actual urban areas and buildings, the Cardiff University Cathays Campus, in Cardiff- Wales, and the Paulista Avenue, in São Paulo- Brazil, were also simulated and contrasted to the urban prototypes scale. A relationship was found between the urban aspect ratios and the ΔCp results. This was demonstrated by statistical methods using the data on the variables concerned, thus verifying the strength of the correlation between them. Strong correlation was found between the investigations into similar scenarios of the urban prototypes and the two case studies as regards both the aspect ratios and the ΔCp results. On the other hand, low correlation for the same variables was identified when contrasting dissimilar urban prototype scenarios.

KEY WORDS *urban environment; aspect ratio; wind pressure; cfd; k-e; and Cp.*

BACKGROUND TO STUDIES ON AIRFLOW IN URBAN AREAS

Flow patterns around isolated bluff bodies are well-known and the basis of knowledge for the calculation of pressure coefficients across buildings and wind loads on structures (Olgyay, 1973; MacDonald 1975; Awbi, 2003; Cook 1985; Holmes 2001). In contrast, the wind field in the urban environment is more complex and less predictable, notably below the canopy height of high-density city centres. According to Cook (1985), when the surface roughness is large and packed, as in towns, airflow detaches at roof height and is channelled in several directions, and will be related to the local neighbourhood buildings shape. General aspects of wind patterns in the urban environment, as compared to those of undisturbed wind, are: mean speed reduction, turbulence intensity increase and greater incidence of weak winds (Ghiaus and Allard, 2005), thought coupling between free and channelized winds is also observed. Urban canyon areas are created by the corridors lying between buildings and are formed by the cavities between the road surface and its flanking buildings, up to roof-top level (Vardoulakis et al., 2003) and the air volume within an urban canyon plays an active role in the definition of the surrounding urban micro-climate and its interaction with the meso-scale climate (Nakamura and Oke, 1988). Studies on the effects of airflows within urban canyons are focused on natural ventilation, the dispersal of air pollution concentration and urban noise, and descriptions for parallel, orthogonal and skewed airflow in simple canyons of infinite length are found in the literature (Wedding et al., 1977; DePaul and Shieh, 1986; Hoydysh and Dabberdt, 1988; Oke 1988; Hunter et al., 1991; Sini et al., 1996; and Santamouris et al, 1999). Effects of slanted flows in intersections and urban areas are reported by Yamartino and Wiegang (1986), DePaul (1986), Hoydysh and Griffiths (1987, in Ahmad et. al, 2005), and Georgakis and Santamouris (2004). Givoni (1976) states that studies with simple shapes based on urban form give an indication of reality such as avoids the interference of other factors in the outcomes, serving as a parameter for other similar, but more complex, urban arrangements. Hunter et al. (1991) describe the important role that the urban geometry plays in the near-surface airflow in urban centres. Several geometric parameters are employed, which are based on linear dimensions, areas and volumes. The proportionality between the building and/or block height (H) and building and/or block length (L) and the road width (W) identifies the built aspect ratio and the type of volumetric canyon within it. It is expected that the resultant airflow speed and direction below the canopy height should be connected to variations in these aspect ratios. These urban ratios are given by the relation between the: building height to road width (H/W) or length (L/H), plan-area density (a= Aroof/ Aurb), and built-area density (b= Abuilt/ Aurb). An urban canyon can be considered uniform or regular when its cross-sectional H/W ratio approximates to 1.0, deep or narrow when this ratio increases to 2.0 and wide or shallow when it drops to 0.5. Also, the canyon length L/H ratio is considered short, medium or long for respective ratios of 3.0, 4.5 and 6.0 (Nakamura and Oke, 1988; Vardoulakis et al., 2003).

THE RESEARCH METHOD

With the aim to verify with which extent the airflow in urban environment results from a combination of built density and the undisturbed wind, and if it can be translated into a matrix of correlation, the research method comprised two steps (de Faria, 2013):

1. The simulation on computational fluid dynamics (CFD) of fifty three urban prototypes with simplified volumetric shape based on eighteen urban arrangements for three wind directions: parallel (0°), orthogonal (90°), and oblique (45°); and
2. The assessment of the airflow in two real urban centres (Cardiff Cathays campus area, Wales; and Paulista Avenue, São Paulo, Brazil) carried out via two (wind tunnel- WT and CFD) or three (WT, CFD, and field measurement- FM) techniques combined and for 8 cardinal and intermediate wind directions.

The groups of urban prototypes

The definition of the proposed urban prototypes covered a variety of urban landscapes, from high to low density, from low building centres to downtown skyscrapers, and was based on the aspect ratios of five areas in the cities of: Cardiff, London, Paris, São Paulo and Hong Kong. The approach covered an area equivalent to that of a circle 500m in diameter from the target building. The systematic variation of the volumetric urban aspect ratio of these prototypes allowed observing the relationship between the built environment and the airflow speed and direction and the wind-driven pressure. Furthermore, these sets of prototypes are not intended to be generally valid or applicable since they have limitations and were created specifically to answer the hypothesis set out in this research. The prototypes were divided into four types: ‘A’, ‘B’, ‘C’, and ‘D’, in accordance with the H/W aspect ratio, and then into four sub-types: 1, 2, 3, and 4, with decreasing plot occupancy density (see Figure 1). While the first two aspect ratios refer to the respective canyon’s linear dimension, the last two refer to areas of several blocks within a pre-established urban perimeter area. From ‘A’ to ‘C’ the scenarios were symmetrical, the height of the blocks was kept constant at 30m, and the division among the types took into account the H/W aspect ratio and the roof and built areas. The length of the blocks also varied from 180m to 30m. The type ‘B-Step’ was a variation of the ‘B-2’ in which half of the blocks had their height doubled in order to assess the impact of step-up and step-down airflows in canyons. Type ‘D’ was also based on the previous sets ‘A’ and ‘B’, but it presented random asymmetry due to height variation of up to three times the previous ones in some of its blocks.

This set sought to represent a more heterogeneous urban scenario. Finally, the 'D-4' scenario presented several detached blocks of 30, 60 and 90m height, thus resembling an urban landscape with high-rise buildings.

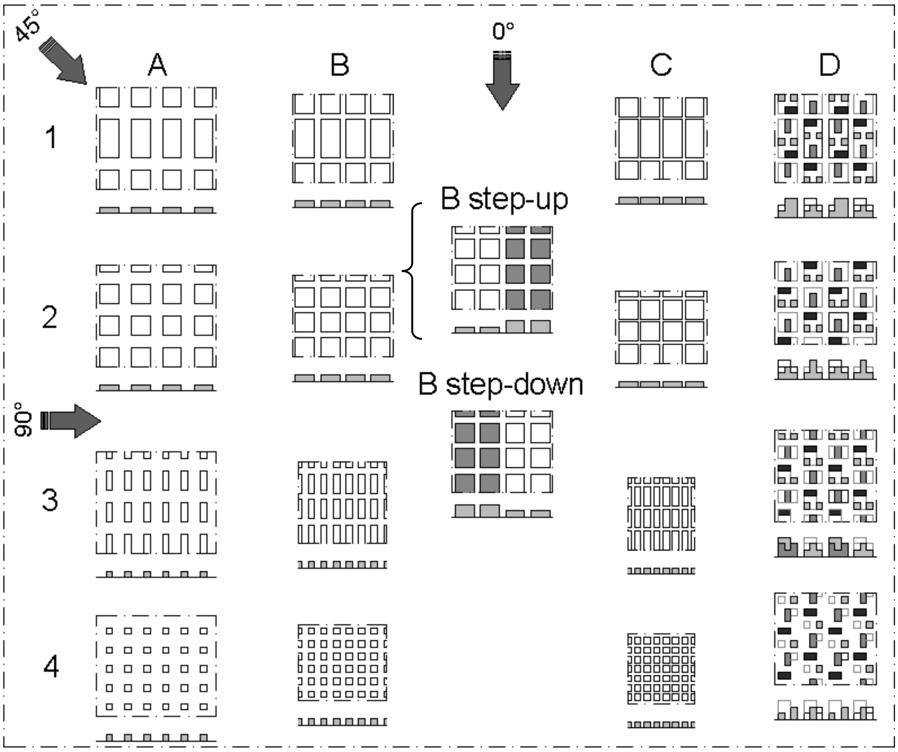


Figure 1 Urban prototype scenarios top views and cross sections and the wind directions.

Table 1. Definition and Characteristics of the Urban Prototype Models and their Equivalence to the Real Urban Canyon Assessed[1] .

	Aspect ratio						A_{roof} / A_{urb}				A_{built} / A_{urb}		
Set	H (m)	W (m)	L (m)	H/W rate	L/H rate	similar to	A_{roof} (m²)	A_{urb} (m²)	rate	similar to	A_{built} (m²)	rate	similar to
A1	30	60	180	0.50	6.0	Cardiff	82,557	196,540	0,42	Cardiff	660,456	3,36	Paris, SP
B1	30	30	180	1.00	6.0	London, Paris, SP, HK	122,604	196,540	0,62	London, Paris	980,832	4,99	SP, HK
C1	30	15	180	2.00	6.0	HK	147,857	196,540	0,75	London, Paris	1,182,856	6,06	-
D1 [3]	30-90	30	180	1.0-3.0	2.0-6.0	London, Paris, SP, HK	122,675	196,540	0,62	London, Paris	1,456,600	7,41	-
A2	30	60	90	0.50	3.0	Cardiff	71,457	196,540	0,36	Cardiff	571,656	2,91	London, Paris
B2	30	30	90	1.00	3.0	London, Paris, SP, HK	109,252	196,540	0,56	London	874,016	4,45	SP, HK
$B2_{up}$	30-60	30	90	1.0-2.0	3.0	Cardiff	109,252	196,540	0,56	London	1,311,024	6,67	-
$B2_{down}$	30-60	30	90	1.0-2.0	3.0	Cardiff	109,252	196,540	0,56	London	1,311,024	6,67	-
C2	30	15	90	2.00	3.0	SP	141,298	196,540	0,72	Paris	1,130,352	5,75	-
D2	30-90	30-60	90	0.5-3.0	1.0-3.0	London, Paris, SP, HK	109,252	196,540	0,56	London	1,277,216	6,50	-
A3	30	60	90	0.50	3.0	Cardiff	40,686	196,540	0,21	SP	325,488	1,66	Cardiff
B3	30	30	90	1.00	3.0	London, Paris, SP, HK	72,436	196,540	0,37	Cardiff	579,488	2,95	London, Paris
C3	30	15	90	2.00	3.0	HK	72,436	196,540	0,57	London	894,448	4,55	SP, HK
D3	30-90	30-90	60-90	1.0-3.0	0.66-3.0	London, Paris, SP, HK	79,358	196,540	0,40	-	1,038,064	5,28	-
A4	30	60	30	0.50	1.0	Cardiff	20,825	196,540	0,11	-	166,600	0,85	Cardiff
B4	30	30	30	1.00	1.0	London, Paris, SP, HK	49,568	196,540	0,25	SP, HK	396,544	2,02	-
C4	30	15	30	2.00	1.0	HK	85,606	196,540	0,44	-	684,848	3,48	London, Paris, SP
D4	30-90	30-90	30-60	1.0-3.0	0.33-2.0	London, Paris, SP, HK	58,500	196,540	0,30	Cardiff , SP, HK	979,200	4,98	SP, HK

Several links between the prototypes and the urban areas may be made (see Table 1). When these links are related to one aspect alone there is a weak connection between them. For instance, if the H/W aspect ratio is considered alone, four urban areas, London, Paris, São Paulo and Hong Kong, have an H/W ratio around 1.0. Conversely, when associated with other criteria, for instance plot occupancy; the first two cities are closer to prototype B1, and the last two to D4, since there is another link as well. In addition, the respective examples present visual compatibility in their urban landscape. In order to confirm whether the built aspect ratio links can be transferred to the results in terms of airflow pressure and velocity

[1] Several H/W and L/H ratios can be found in the D1, D2, D3, and D4 prototypes since the geometry and volumes are asymmetrical and heterogeneous, and an averaged value based on the several dimensions in the model is used for calculating the related urban aspect ratios.

decrease within these urban areas, two of these sites, Cardiff and São Paulo, were selected for further investigation. Both of these places could provide essential information to verify the accuracy of the proposed method. Further, neither Cardiff nor São Paulo matched accurately a prototype in all three criteria. This may help to bring out whether one of the criteria is stronger than the other in the relation between built mass and the resultant airflow field.

The case studies

The two urban areas selected for the case study were: Park Place on the Cardiff University Cathays Campus area (Figure 3); and the Paulista Avenue, in São Paulo (Figure 4). As case studies, both areas were simulated by CFD and wind tunnel, while field measurements (FM) were only performed in the former[2]. While the Cathays Campus neighbourhood is considered a low-density area with mostly three-floor low buildings close to open areas such as Alexandria Gardens and Bute Park, in contrast, the urban site and immediate surroundings of Paulista Avenue, located on a hill-crest at the core of the City of São Paulo, is characterized by high-density land occupation and high-rise buildings, with this avenue being one of the most important financial poles in Brazil.

The computational fluid dynamics (CFD) simulations

The CFD programme used in this investigation was a research version of the ANSYS FLUENT 6.2 and the 3D models were built and meshed in the Gambit 2.0 software. Although CFD results are susceptible to uncertainties and approximations, the achievement of consistency and reliability in the outcomes is related to the control of a number of input and calculating parameters, which is achieved by following standard procedures and performing pre-test simulations for calibration, verification and validation of the results[3]. These procedures and tests, and the steps taken during the CFD stages of modelling, pre-processing, solving and post-processing are described in de Faria (2008) and de Faria (2013). This practice was used to ensure consistency in the modelling for all the three groups of CFD calculations undertaken: the calibration of the CFD input and modelling parameters itself; the investigation of the urban prototypes; and the assessment of urban areas approached as case studies. In the CFD pre-processing stage the 3D model input is specified, which involves decision making about the domain discretization, size and verifying the impact that the boundaries specification, the mesh type and size, the mesh adaption, the fluid properties, the cell blockage and other aspects of the problem description may have on the results. The solution to this imposed problem is calculated during the CFD solving stage. The turbulent viscosity model adopted for all the CFD simulations was the k-e RANS standard. Several steps involving the solution control parameters, such as the choice of the time mode; thermal mode; turbulence model; solution controls; relaxation factors; monitoring solution progress; and residual plot thresholds, may interfere in the quality of the simulation and, in consequence, in the reliability of the results. In order to analyse the CFD results, airflow pathlines were used for visualizing the airflow field through the blockages. The quantitative data from the CFD output were extracted either from lines (data about wind velocity (magnitude, ‘x’, ‘y’, or ‘z’ vectors) or from surfaces (Cp values). The data were exported from the export panel as comma delimited in the ASCII format and imported into the Excel software.

Correlation coefficients and the scale of significance for urban aspect ratios

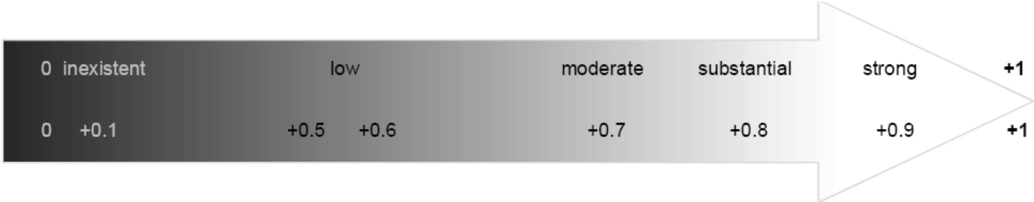
The correlation coefficient identifies the number of relationship between two sources of quantitative variable data, thus ascertaining the statistical strength between them. The Pearson *r* model provides a scale of significance for correlation coefficients. This scale is a linear association between standard product-moment sources of data. The correlation coefficient ‘*r*’ equation, based on series of data ‘x’ and ‘y’ and

[2] Only the CFD results are presented in this paper. Further information is available in de Faria (2013).
[3] The calibration, verification and validation of the parameters used in the CFD investigations were attained by calculating the flow field around two parallel rectangular bricks and contrasting the results with those of the wind tunnel physical model (de Faria, 2013).

employed here, is given by Barrow (2009). The values on this scale range from +1.00 to -1.00, on which zero means absence of correlation (Warner, 2008; Barrow, 2009; Kottegoda and Rosso, 2009; Croft and Davidson, 2010). Several correlation analyses were employed in this investigation in order to reveal a number of associations between different models, such as: the level of diversity among the several urban prototype's physical dimensions and aspect ratios adopted; the variety of ΔCp results among the several urban prototypes; the urban shape/ aspect ratio's similarity strength between the several urban prototypes and each case study investigated; and the ΔCp results' similarity strength between the several urban prototypes and each case study investigated. By comparing the correlation coefficients for the urban prototype's Groups 01 to 06 it was possible to observe that for those from the same group (e.g. A1, A2 and A3; B1, B2 and B3...) a correlation relationship from 1.00 to 0.94, while the ones from an adjacent group (e.g. A1 and B1, A2 and B2; A3 and B3...) present a correlation relationship from 0.94 to 0.91. This shows that the systematic variation of the aspect ratios for these simplified scenarios was obtained in a balanced gradient between prototypes both intra and inter-group. Conversely, when comparing dissimilar scenarios, such as A1 and D4, and A4 and C1, the relationship was 0.66 and 0.45, respectively. By comparing the urban prototype aspect ratios and the two case studies aspect ratios, a scale of significance for correlation coefficient strength of physical dimensions in the urban environment is presented (Figure 2). Although Pearson's model is frequently applied in civil and environmental engineering investigations and in the field of the Sciences of Technology, including models for spatial correlation (Kottegoda and Rosso, 2009), a scale such as would determine the strength of the correlation which is compatible with this investigation could not be found in the referenced literature reviewed (Warner, 2008; Barrow, 2009; Croft and Davidson, 2010). Further, the correlation strength scales provided by the Social or Biological Sciences literature are not appropriate for this application[4], since they are specific to those fields and thus do not match the scale of results from this research area. On the other hand, the urban prototypes proposed in this investigation were based on urban aspect ratios of actual urban areas and that several links between them were identified. For instance, when observing the urban landscapes of the two case studies investigated in depth it is possible to associate the Cathays Campus with the urban prototypes A and C, while the Paulista Ave. is more closely similar to the urban prototypes D3 and/ or D4. Therefore, for the five cities assessed in the urban area analysis, the Cathays Campus would be positioned on one side of the scale, characterized as a low-height built-up area, whilst the Paulista Ave. would sit on the other side, as a high-rise built-up area, with both landscapes representing the extremities of this scale. Based on this hypothesis, it is to be expected that results between Cathays Campus and prototypes A and/ or C will present a strong correlation while results between Cathays Campus and prototypes D3 and/ or D3 will present a weak correlation, with the opposite occurring with the Paulista Ave. Indeed, the correlation coefficient between the Cathays Campus aspect ratios and the urban prototypes previously related to have similarities in their landscapes, such as A1; A2; A3; B1; B2 and B3 showed correlation coefficients of 0.94; 0.87; 0.91; 0.85; 0.80 and 0.82, respectively. In contrast, the correlation coefficient between the Cathays Campus aspect ratios and the urban prototype with opposite landscape features (D4), on the other edge of the scale, was the lowest found: 0.51. The correlation coefficients between the Paulista Ave. and the urban prototypes aspect ratios seen on Table 4 showed a relationship of 0.95 and 0.90 with the urban prototypes D4 and D3, respectively, which belong to the Group 6 prototypes scenarios and were previously described as having the most similar urban landscape features. Once more, the urban prototype previously defined as the opposite one to this high-rise building urban landscape presented the lowest correlation coefficient: 0.53 (A1). This lowest result was followed by the ones obtained with C1 (0.52) and B1 (0.58). Again, the similar and the dissimilar urban landscapes were positioned in opposite edges of the scale. Therefore, the correlation coefficient found between these will serve as a standard for the scale of significance for this exercise. Based on the findings the scale of significance for assessing and comparing

[4] For instance, De Vaus (2002) ranks the correlation coefficients for Social Science researchers as follows: 1.00= perfect; 0.99 to 0.90= near perfect; 0.89 to 0.80= very strong; 0.79 to 0.70= strong; 0.69 to 0.50= substantial; 0.49 to 0.30= moderate; 0.29 to 0.10= low; 0.09 to 0.00= trivial; while a negative result implies in a reverse correlation, *in* De Vaus, D. 2002. Analyzing Social Science Data. London: Sage.

urban landscapes' physical aspect ratios correlation coefficient strength proposed in Figure 2 provides four ranks for the Pearson's correlation scale of significance: strong, substantial, moderate, and low. For the urban aspect ratios analysis, this means a range of correlation coefficient ranging from 0.95 to 0.51. In the following topic, this scale will serve as a reference for ranking the ΔCp level of association and correlation coefficient strength. It is expected the ΔCp results to follow the same sequence as this scale, though not of the same order of magnitude.



a)

PROTOTYPES

CARDIFF	D4	C4	A4	B4	D3	C2	C3	C1	D2	D1	B2	B3	B1	A2	A3	A1
rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
r	0,51	0,53	0,59	0,59	0,62	0,62	0,62	0,65	0,68	0,78	0,80	0,82	0,85	0,87	0,91	0,94

PROTOTYPES

PAULISTA	A1	C1	B1	C3	C2	D1	A3	A2	B3	B2	D2	C4	D3	A4	B4	D4
r	0,52	0,53	0,58	0,60	0,60	0,61	0,65	0,68	0,69	0,70	0,80	0,81	0,90	0,92	0,95	0,95
rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

b)

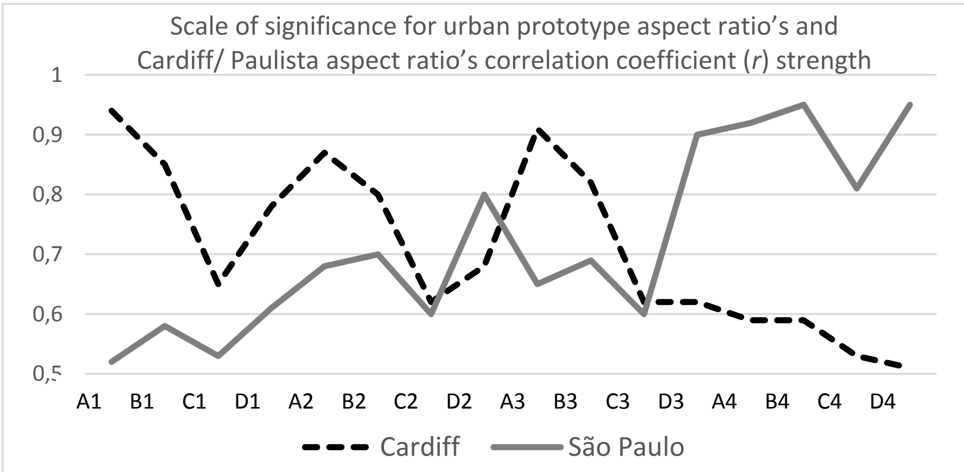


Figure 2 The scale of significance for urban prototype aspect ratio's and Cardiff/ Paulista aspect ratio's correlation coefficient (*r*) strength (a) and illustrative graphic (b).

RESULTS

Correlation coefficients and the scale of significance for ΔCp results

Here this investigation seeks to identify if the correlation coefficients found for the aspect ratios between the Cathays Campus (targeting the Law School Building external façade, situated on the Museum Ave. and the Park Place) and the Paulista Ave. (CYK Tower) with the Groups 01 to 06 of the urban prototypes, may also be translated into ΔCp results.

The Cardiff University Cathays Campus

The ΔCp results for Cathays Campus, when contrasted to the Prototype A1 (Figure 3), whose correlation for aspect ratio was of 0.94, showed also strong correlation of 0.90 for S winds (at 45º to the Museum Avenue external side) and substantial correlation for SE (0.83) and NW (0.78) - both at 0º. In contrast, the wind directions from E (0.53), N (0.36) and W (0.33) - the three at 45º - presented moderate to low correlation, while the ones from NE (-0.30) and SW (-0.68) - both at 90º - showed low to moderate reverse correlation. Both the equivalences and disparities found between the aspect ratio and the ΔCp results correlation coefficients may occur due to the 'V' shape of the Law School Building which forms a courtyard at an angle of 45º with side high-rise buildings has an impact on both the airflow velocity and the ΔCp results. On the other hand, when contrasted to the Prototype A2, whose correlation for aspect ratio was of 0.87, the correlation for the NE and SW winds - orthogonal to the façade – raised to 0.22 and 0.55, respectively. And when compared to the contrasting D2 prototype, whose correlation for aspect ratio was of 0.68, the correlation found for the E wind raised to 0.62.

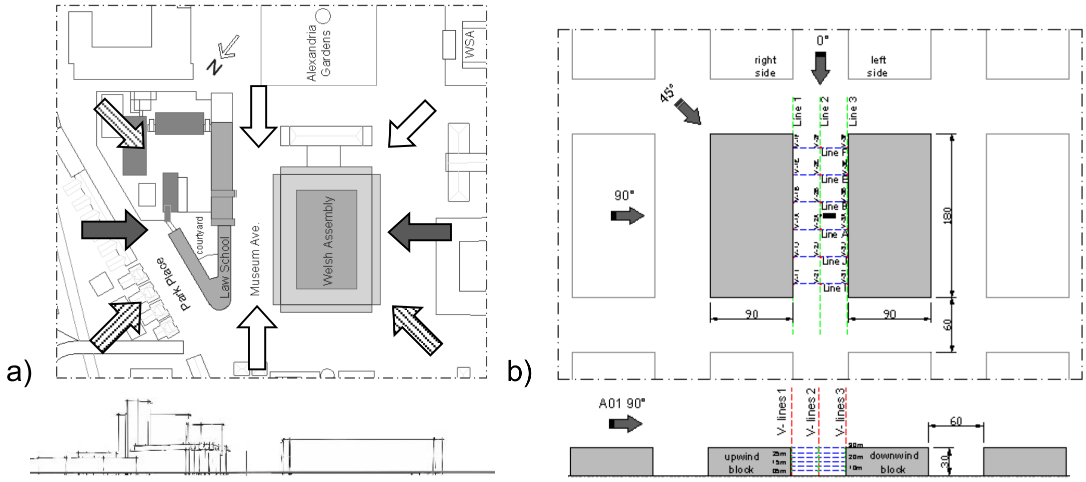


Figure 3 The arrows point the wind direction and show: strong (white), low (lines) or reverse (black) correlation strength between (a) the Cardiff Cathays area and (b) the Prototype A1 ΔCp results.

CYK Tower and the Urban Prototypes correlation assessment

Strong correlation was found between the Paulista Ave. and the urban prototype D4 on both the aspect ratio (0.95) and the ΔCp: 0.91 for NE (0º), 0.90 and 0.94 for N and S (90º), and 0.92 and 0.93 for NW and SE (45º) winds (Figure 4). Further, at least two out five wind directions with the same rank for the other prototypes from the Group 6 (D1, D2, and D3) also showed strong statistical similarity to the Paulista Ave. The prototype scenarios A1, A3, C3, and C4 showed substantial statistical similarity, while all the other prototype scenarios showed from moderate to low relationship levels.

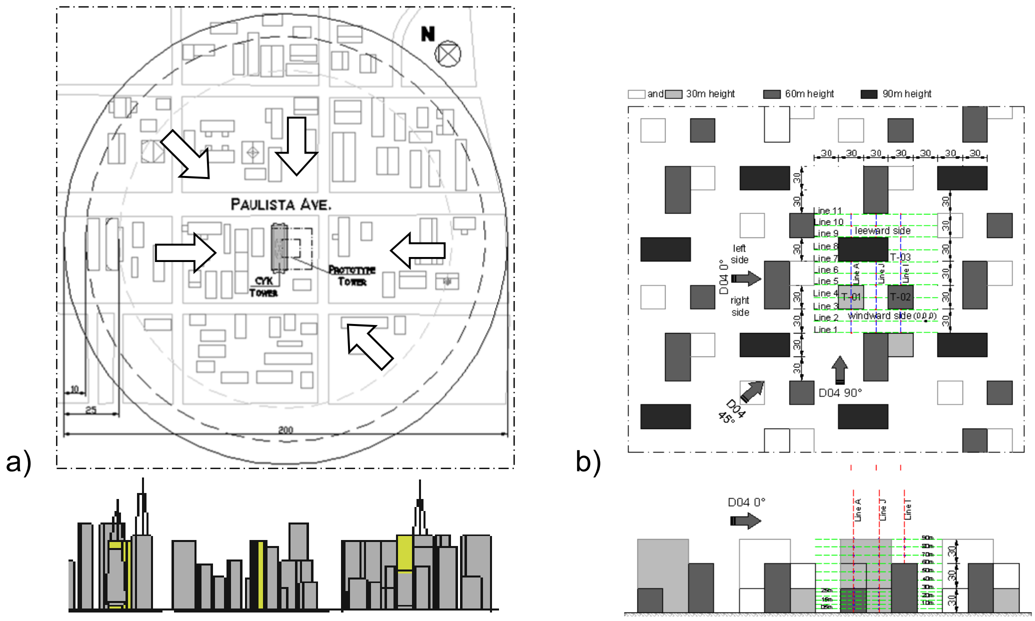


Figure 4 The arrows point the wind direction and show: strong (white), low (lines) or reverse (black) correlation strength between (a) the Paulista Ave. and (b) the Prototype D4 ΔCp results.

CONCLUSION

A large number of CFD simulations involving urban prototypes and two case studies was performed aiming to verify the strength on the relationships between the built environment and the ΔCp distribution in several urban scenarios for parallel, perpendicular and oblique wind directions. Both the H/W and the Abuilt/ Aurb aspect ratios on the windward side of the target area are mandatory on the definition of the airflow field and the Cp on the buildings envelope. A comparison of Cathays Campus ΔCp results showed strong correlation between this actual urban area and the comparable prototype A1 for three wind directions, while other three showed moderate to low correlation. Contrastingly, a stronger link was found with overall dissimilar prototypes but whose urban shape is related to this real urban area on its windward side. The combined analysis between the Paulista Ave. and the D4 prototype showed strong statistical strength between both the physical aspect ratios and the ΔCp results for five wind directions assessed. This is consistent with the hypotheses and the objectives of this investigation. Based on these findings it may be affirmed that the relationship between the various physical dimensions which characterize the urban environment in terms of its urban aspect ratios have proved to be related to the resultant ΔCp in buildings when associated with air flow data. Therefore, it seems possible to create an empirical scale that permits to estimate the ΔCp results. Although such method requires further research and validation before its application as a practical tool, such scale would be helpful for architects, building engineers and urban planners on designing naturally ventilated buildings.

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Session 1C : User behavior, thermal comfort & energy performance

PLEA2014: Day 1, Tuesday, December 16
11:30 - 13:10, Grace - Knowledge Consortium of Gujarat

Daylighting for Visual Comfort and Energy Conservation in Offices in Sunny Regions

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ABSTRACT

Office buildings in regions with abundant sunlight may still fail to make effective use of daylight: the difficulty in controlling variations in natural illumination, which may be substantial, often results in extensive use of artificial lighting. A solution to this paradox was sought by means of a controlled experiment designed to investigate the effect of several strategies to reduce glare and to achieve visual comfort in a test room configured to represent a typical side-lit office. Subjects performed office tasks such as reading or operating a computer, and completed a detailed questionnaire about their work environment, whose physical parameters were monitored in great detail. The study showed that if the window is exposed to direct sunlight, the use of tinted glass may not be an adequate response. Internal Venetian blinds, if deployed correctly, may prevent glare and provide visual comfort to workers near the window – but they require frequent adjustment and reduce the depth at which daylighting may still be enjoyed. A light shelf with an exterior part to shade the view pane from direct sunlight in summer and an interior part to reflect light to the ceiling resulted in superior daylighting and better visual comfort in all room configurations. It is suggested that since windows in offices fulfil multiple roles (daylighting, natural ventilation and a view outdoors), their functioning could be improved by subdividing them into panes to optimize their provision.

INTRODUCTION

Lighting comprises a significant part of the energy used in office buildings: Estimates range from 35% in Adelaide, which has a mild sunny climate (Blanchard, 2005), to 23% in cooler, overcast London, where heating requirements are greater (Majoros, 1998). Because office buildings are occupied mostly during the daytime, the potential for energy savings through substituting daylighting for electric lights is high. Simulation studies of typical office spaces in Belgium (Bodart and De Herde, 2002) show that approximately 40% of this energy can be saved by automatic dimming of artificial lighting when sufficiently illumination can be achieved by daylighting alone. Demonstration buildings have shown that energy consumption for lighting and HVAC can be reduced by 50% (Voss *et al*., 2005), but savings depend on the proportion of occupants that have access to external windows and on the ratio of window area to floor area (Krarti *et al*., 2005).

The predominant strategy for increasing daylight utilization has been to design extensive glazed

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facades. However, when the sun is out, a person near the window may be exposed to high, asymmetrical radiant loads and very high levels of illumination: mean radiant temperatures of up to 47°C and illumination levels in excess of 30,000 lux were measured indoors near a clear window on a sunny winter day (Erell *et al*., 2004). To counter this, the occupants of such buildings may require curtains or blinds to avoid glare or overheating. Unfortunately, they typically leave their blinds deployed at all times, and employ electric lighting even when external illumination levels are sufficient to provide adequate illumination. In warm sunny locations this behaviour results in a double penalty: First, because in summertime external gains from a glazed area are greater than from an opaque wall; and second, because the use of electric light increases internal gains and increases the load on the A/C system.

Visual discomfort caused by excessive light is referred as 'glare', defined by the CIE as the "condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or extreme contrasts". Evaluation of glare is sometimes not straightforward, as most traditional indices for visual comfort encounter difficulties either at extreme luminance levels or in the evaluation of large sources of light or sources not mounted close to the ceiling plane, such as vertical windows (Osterhaus, 2005). If the potential sources of glare cover a significant part of the visual field of the observer, the adaptation of the eye to higher luminance reduces the glare sensation and contrast effect. When the glare source is small, however, the observer's adaptation level, which is determined by the luminance of the background, is virtually independent of the light source.

The Daylight Glare Probability (DGP) is probably the index best-suited for highly luminous environments. It is based on the vertical illuminance at the eye as well as on the luminance of the glare sources, their solid angle and their position index. The DGP, which was calibrated empirically on the basis of controlled experiments at Freiburg and Copenhagen, has values that range from 0 to 1, and is calculated as follows (Wienold and Christoffersen, 2006):

$$DGP = 5.87 \cdot 10^{-5} \cdot Ev + 9.18 \cdot 10^{-2} \cdot \log\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_s}{E_v^{1.87} \cdot P_i^2}\right) + 0.16$$

where E_v is the vertical illuminance at eye level [lux], L_s is the luminance of the *i*th source contributing to the glare [cd m^{-2}], ω_s is the solid angle subtended by the source and P is the dimensionless Guth position index.

An index incorporating a probability is preferable for most rating schemes, since there is a large variation of responses when comparing visual comfort, especially with respect to glare Osterhaus (2005). Thus, a 100-fold increase in luminance may be required to arrive at the same subjective glare rating between the least sensitive and most sensitive subjects (Osterhaus and Bailey, 1992). Furthermore, responses of individuals are often inconsistent when assessing the same environment on different occasions. This may be due to acclimatization to current daylight levels outdoors, which vary greatly on a daily basis but also between locations. For example, illuminance levels of over 75,000 lux occur on nearly two-thirds of the days in Tel Aviv, but barely on one day in ten in Berlin. The search for a universal index is further complicated by the fact that there are apparently persistent cultural differences in illuminance preferences (Belcher, 1985). Indeed, Veitch and Newsham (1996) suggest that the perception of lighting quality is affected by behavioural factors that are not accounted for in any of the existing indices. Nonetheless, current standards for lighting – artificial or natural – make no allowance for such disparities among countries, or for other sources of individual and contextual variability.

Much of the research on daylighting has been carried out in overcast locations, and the current study seeks to complement this body of knowledge in a highly luminous environment. Its aims are to evaluate several daylight control systems in such locations, and to evaluate the use of the DGP for subjects acclimatized to these kinds of lighting conditions.

METHODOLOGY

A controlled experiment was carried out to investigate occupant preferences with respect to several façade designs for better visual comfort and glare control. The test subjects were asked to perform several tasks representing typical office work, such as reading from paper and typing to a computer, in a room furnished to resemble a normal office. Measurement of light – luminance and illuminance – was carried out concurrently in a second adjacent room where conditions were almost identical. The position of the work station and its orientation with respect to the window were varied according to a predefined schedule. To reduce the possibility of inadvertent bias because of minor differences between the rooms, the roles of the two rooms were alternated. The subjective responses to a questionnaire were analysed and compared to prevailing conditions during the test sessions.

Test rooms

The test rooms were 2.7m by 3.5m wide and 3.05m high, with white walls and ceiling (reflectance 0.75), and a terrazzo floor (reflectance 0.45). An aluminium-framed window 1.34m wide by 1.76m high was located near the middle of the (long) south-facing wall. The windows comprised a 'view pane' consisting of horizontal sliders 114cm in height beginning 95cm above the floor, and a fixed 'daylighting pane' 62 cm high above them. An external roll-down shutter remained open for the duration of the tests. Both test rooms were furnished with identical computer work stations installed on small tables fitted with wheels, to allow easy repositioning by test subjects. Each station included a personal computer with a 19" LCD monitor, keyboard and mouse. Walls were decorated with coloured posters to enhance the visual environment and to reduce glare from uniform white surfaces, simulating a real office.

Daylight control strategies

Three daylight control strategies were tested, singly and in combination:

1. *Tinted glass*: The use of tinted glass is widespread in office buildings in most sunny locations, both to reduce solar gains (so-called ‘solar control’ glazing) and to reduce glare near the windows. The view pane of the window was fitted with either clear double-glazed panes (VT=0.79) or with similar panes equipped with a tinted foil with a total light transmittance of 0.47 (VT47).
2. *Venetian blinds*: Venetian blinds are the most common internal shading device found in offices. The window was equipped with standard white blinds with curved slats (25mm wide, 1.5mm curvature) that covered the entire glazed area. After installation of the light shelf (see below), these blinds covered the view pane only.
3. *Light shelf*: A ‘portable’ light shelf comprising an internal element and an external one was attached to the window at a height of 2.1 meters above the floor (Figure 1a and b). The shelf had a curved section (convex on the interior, concave on the exterior), was 50 cm deep and extended 20cm beyond each side of the window.

Figure 1 Light shelf installed for the experiment, seen from interior (left) and exterior (middle); setup for HDR photography used to establish luminance (right).

Monitoring internal environmental conditions

While subjects were carrying out the test procedure, the following parameters were monitored:

- Indoor air temperature, relative humidity and CO_2 concentration
- Indoor illuminance: 4 horizontal measurements of general room lighting - 10 cm above desk as well as half a meter from wall centres (TES-1332A light meter), each of which received different amounts of light; Illuminance at the task area (vertically next to the computer screen and horizontally on the keyboard); Vertical illuminance at the eye; Total exterior illumination received at the window (on a vertical plane) and the net flux transmitted to the interior, adjacent to the window pane (or 10 cm behind the venetian blinds when these were in place).
- Indoor luminance was evaluated from HDR images taken from the subjects' eye position looking towards the task area and the window (with a Coolpix 5400 camera and FC-E8 fish eye lens, Figure 1c). Images were calibrated using spot measurements (Minolta luminance meter LS-110).
- Outdoor horizontal illuminance (TES-1332A light meter)

Questionnaire

The subjective sensation of glare experienced by the participants in the controlled daylighting experiment was recorded by means of a questionnaire consisting of 4 sections:

a. Personal (demographic) questions
b. Subject assessment of the rooms and quality of the visual environment
c. The subject's explanation of their individual preferences in setting up the subject-defined test environment
d. Questions on subject's perception of indoor climate within the room

Experimental procedure

Experiments in the test rooms at the Sde Boqer campus of Ben-Gurion University (30.8 N 35.1E) took place between October and March at 10:30-15:00. Sessions were conducted only on sunny, cloudless days, characterized as a CIE Standard Clear Sky (Type 12), with a (vertical) illuminance on the window in excess of 50,000 lux. Each subject was asked to carry out a sequence of tasks and to fill in questionnaires to obtain a subjective rating of the visual comfort of the simulated office environment. While the subjects were thus occupied, research staff carried out measurement of the visual environment in the second adjacent test room, which was identically oriented and equipped.

The subjects were requested to follow instructions given in an interactive PowerPoint presentation. This provided the basic structure of the experiment, as follows:

1. After carrying out typing tasks requiring them to copy text from both the screen and from paper, in order to become acquainted with the procedure, subjects were asked to fill in a questionnaire with basic demographic information.
2. The test room was then arranged in the first test configuration, according to a predetermined schedule established to test all possible combinations of desk location relative to the window and of the daylight control strategy. The subjects then performed the first test unit: They watched one of three short videos, to allow them to become acclimatized to the new visual conditions, then performed two typing tasks and finally answered a questionnaire to give their assessment of the visual environment.
3. The test room was then arranged in a second configuration by changing the glazing type. The subjects then performed the second test unit, which was identical to the first one.
4. After completing the second test unit, subjects were asked to arrange the test room so as to maximize comfort. They were allowed to choose either type of glazing, to select any location in the

room for the computer work station, and to manipulate the venetian blinds to any position. Following this, they performed the third test unit.

5. After completing all three test units, the subjects answered one final questionnaire to give their overall assessment of the work environment in general.

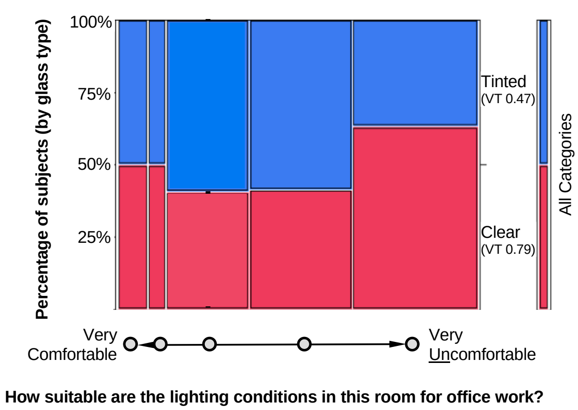
RESULTS

A total of 59 subjects completed the entire survey procedure. Subjects were mostly students and faculty at the Blaustein Institutes for Desert Research, between the ages of 17 and 48 (average age 31), equally divided by gender and from diverse ethnic backgrounds. One third of the subjects wore glasses.

Effect of Tinted Glazing

The total number of surveys for clear and tinted glass was the same. Questionnaire findings indicated that installation of tinted glass improved overall satisfaction with the visual environment. However, as the mosaic plot in Figure 2 shows, in spite of much lower levels of illumination in the room, the majority of respondents (as indicated by the width of the two right-most bars) still rated the office as either ‘very uncomfortable’ or ‘somewhat uncomfortable’, irrespective of the type of glass (indicated by colour – red for clear and blue for tinted). The main contribution of the tinted glass appears to have been to mitigate the extreme condition somewhat: Only one third of subjects who rated the office very uncomfortable did so when tinted glass was installed – but almost 60% of those who rated the office ‘somewhat uncomfortable’ did so in spite of the presence of tinted glass.

The Daylight Glare Probability, estimated using digital HDR images of the test office with tinted glass, is significantly lower than for clear glazing (Figure 2, right). However, even though the reduction in the visible light transmission of the glazing is 40 percent, compared to the standard clear glazing used as a reference – the median value of the DGP index was still over 40%, indicating that close to half of the occupants would be likely to suffer from glare in such conditions. In other words: In luminous climates such as Israel, even very substantial reductions in the visible light flux are not, in themselves, sufficient to prevent glare.



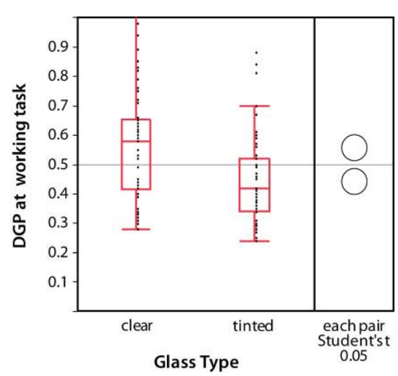


Figure 2 Effect of tinted glass on visual comfort responses of subjects. Left: Mosaic plot of subjective responses from questionnaires. Right: DGP predicted by analysis of luminance from HDR images of subjects' field of view when facing the computer display.

Effect of Venetian Blinds

Subjects were offered the option of deploying Venetian blinds either in conjunction with other light control means such as tinted glazing (with or without a light shelf) or as the only method of controlling exposure to daylight. The degree of exposure to daylight was determined by the subjects, who were allowed to deploy the blinds according to their personal preference, manipulating both the angle of the slats and the proportion of the window shaded (by lowering or raising them). After the position of the blinds was fixed by the subject, the illumination levels in the test room were measured by a technician, who then manipulated the position of the blinds in the reference room to obtain identical illumination levels throughout the room. The subjects were allowed to begin their evaluation of the specific configuration of blinds only after this calibration procedure was completed satisfactorily, and the full set of measurements could be carried out in the reference room.

The responses of the subjects who were allowed to deploy venetian blinds were in very good agreement with the predicted evaluation of the visual environment given by the DGP index. Analysis of the questionnaire indicated that when the venetian blinds were deployed, subjects were in fact almost always satisfied with the resulting visual environment, with only a very small proportion still rating conditions as either 'somewhat uncomfortable' or 'very uncomfortable' (Figure 3). Although the combination of tinted glass and venetian blinds was slightly more likely to produce 'very comfortable' conditions than Venetian blinds alone, the contribution of tinted glass to obtaining merely 'comfortable' conditions was negligible. Subjects who gave this evaluation were equally likely to have clear glass as tinted glazing.

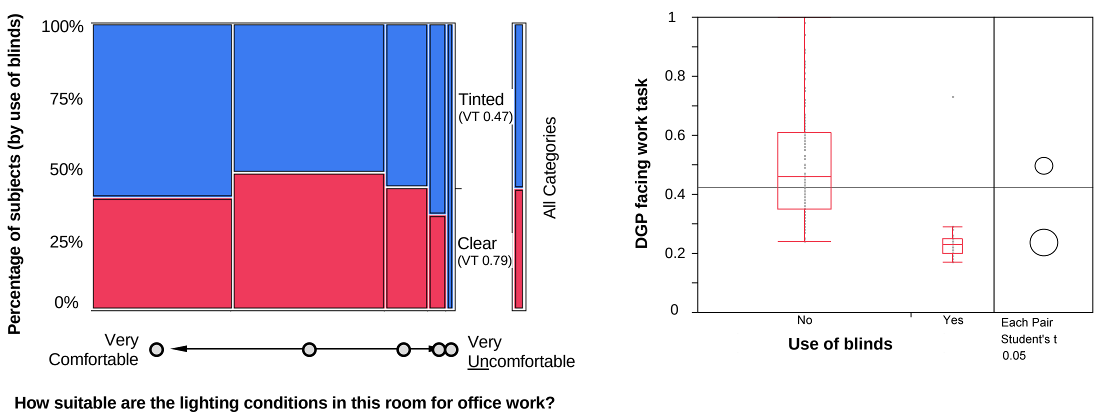


Figure 3 Effect of Venetian blinds in combination with clear or tinted glass on visual comfort responses of subjects. Left: Mosaic plot of subjective responses from questionnaires. Right: DGP predicted by analysis of luminance from HDR images of subjects' field of view when facing the computer display.

Effect of Light Shelf

The role of a light shelf is to redirect sunlight to modify its distribution in the room, and to provide partial shading in hot weather. The experiment evaluated the effect of a light shelf comprised of both an external element and an internal component on the light distribution in the room, with the venetian blinds either deployed or not. The subjects' evaluation of the resulting illumination was recorded as part of the questionnaire they were asked to fill.

When the Venetian blinds were not deployed the light shelf reduced the light level on the desk significantly. In this mode, its primary role was as a shading device, blocking part of the direct sunlight impinging on the window. As Figure 4 (right) shows, the light shelf reduced median illumination in the room from over 13,000 lux to about 3,500 lux. However, in spite of the reduction in illumination caused by the light shelf, for much of the time light levels were still well above recommendations for visual comfort, both on the desk and on the computer display. Thus, although the light shelf reduced the probability for glare substantially, it by no means eliminated it: the median value of the DGP was 39%, compared to 57% with no light shelf. In sunny conditions when solar elevation is low enough to allow substantial penetration of direct sunlight, additional shading (such as blinds or curtains) may be required for the lower part of the window. When Venetian blinds were deployed, the primary role of the light shelf was to improve light distribution in the room, providing substantially higher levels of illumination in areas not adjacent to the window (Figure 4, left). More importantly, although the light shelf led to median light levels that were twice as high as for window equipped with Venetian blinds only, the probability for glare, as measured by the DGP indicator, remained very low.

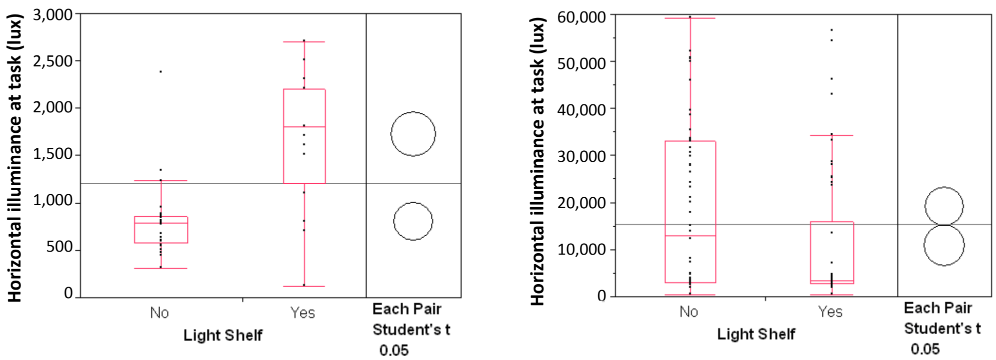


Figure 4 Effect of light shelf on horizontal illuminance of work surface. Left: with Venetian blinds deployed on view pane of window. Right: without blinds.

DISCUSSION AND CONCLUSIONS

The effect of tinted glazing on visual comfort was quite modest. The almost universal use of such glass in office buildings in sunny locations, and its wide application even in overcast ones, should not obscure the fact that even low levels of light transmission do not guarantee comfort.

Venetian blinds are known to be an effective means of controlling penetration of direct sunlight to the office interior, and the ease with which occupants can manipulate their position is a great advantage compared with most other forms of solar control. This suggests that if occupants of small offices take sufficient care in adjusting the position of the blinds, taking into account both the extent of deployment (or proportion of the window left fully exposed) and the angle of the slats – they can enjoy the benefits daylight without being exposed to glare. However, Venetian blinds are not a panacea: maintaining visual comfort with natural light requires frequent adjustment of the blinds in response to changing quantity and quality of external light: variations may be the result of changing weather or cloud cover, but also because the diurnal path of the sun that means a window may be illuminated by direct sunlight for only several hours of each day. The findings of a field survey (Erell and Kaftan, 2011) suggest, however, that such continuous adjustment is rarely carried out in practice. Furthermore, while work stations adjacent to the window may be well-served by Venetian blinds, work areas located further away might require artificial light if the blinds are deployed in response to conditions near the window. This is exacerbated if so-called 'solar control (tinted or reflective) glazing is installed to reduce overheating.

As this study has shown, having a light shelf is beneficial both when the venetian blinds are deployed, and when they are not. In the former case, they reduce illumination levels which might otherwise be excessive, thus reducing glare. In the second instance, they increase illumination levels, especially in parts of the interior not adjacent to the window – without increasing the probability for glare. A light shelf with blinds deployed below it provides high quality daylight: reducing glare in the working area adjacent to the window while enabling higher illuminance levels deeper in the office.

Therefore, a fundamental daylighting solution for buildings in sunny climates may consist of an upper daylight window, a lower view window, a light shelf, and daylighting control systems (such as blinds).

Although it is beyond the scope of the present paper, it may be noted that the experiment also demonstrated that the relation of the working position to the window also has a great bearing on visual comfort. The worst orientation is facing the window, whereas lighting from the side or diagonally results in less glare. However while the desk position may, on its own, mitigate glare to some extent, additional means such as daylighting control systems were still required in sunny conditions.

Daylighting design is frequently concerned with obtaining sufficient light, typically measured by metrics such as illuminance of a horizontal work surface or a daylight factor. These indicators ensure that a minimum level of natural light is obtained, contributing to health and alertness. However, these measures are insufficient when it comes to predicting visual comfort – which is better assessed by means of the Daylight Glare Probability. The calculation of this last metric requires detailed information and appropriate computer software, but demonstrated a very good correlation with subject responses in this experiment.

ACKNOWLEDGMENTS

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Improving Outdoor Urban Environments: Three Case Studies in Spain

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ABSTRACT

Public life is as intrinsically linked to the physical and material settings as it is to the climatic environment. The physical properties of a space, such as materiality, temperature, or light, can enhance or inhibit people from using and enjoying it. When architects and urban designers deal with the physical properties of a space, and therefore modify its material, thermal, and lighting characteristics, they influence the social environment as well. This paper describes a field study undertaken in Spain. Its aim was to understand the implications of climate-responsive design in urban public spaces over the physical, climatic, and social environment. Three case studies in Spain were selected and the resulting climatic and social environment analyzed. The three structures are: Metropol Parasol in Seville, Ecobulevar in Madrid, and Plaza Pormetxeta in Barakaldo. Each of the three case studies is located in a different climatic region within the Spanish geographical context. The study included on-site measurement of climatic conditions and observations of people behaviour in the public spaces. These were correlated and compared to nearby public spaces to assess the success of the structures in creating lively urban areas. The study suggested that, while climatic conditions play a key role in the success of public spaces, climate-responsive design must also consider other aspects of urban design such as social activities, accessibility, preconceptions of the space, and visual delight.

INTRODUCTION

During the last decade, Spanish cities have witnessed the proliferation of climate-responsive structures, such as canopies or wind towers, in their outdoor public spaces. The main purpose of such structures was to adapt these spaces to existing microclimatic conditions and promote outdoor comfort. In many Spanish cities, staying outdoors in summer at midday can be too uncomfortable and even dangerous. This is due to high temperatures and intense solar radiation that are intensified by the Urban Heat Island effect and climate change. Some studies have analyzed the effects of the structures over the climatic conditions around them (Soutullo et al., 2007). However, no research has addressed their effects on the use of the public space by citizens. What have not been assessed yet are the implications of climate-responsive structures for citizens' everyday lives. By studying people's perceptions and reactions to these structures, climate-responsive design could be improved to fulfil its ultimate aim: to promote the use of public spaces. Architects and urban designers should follow an integrative approach to the design of public spaces, one that combines the search for a comfortable environment through climate-responsive design, with a lively social environment that improves the quality of life within cities.

The study described in this paper analyses the resulting climatic and social environment of three climate-responsive structures in Spanish urban public spaces. The three structures are: Metropol Parasol in Seville, Ecobulevar in Madrid, and Plaza Pormetxeta in Barakaldo. Each of the three case studies is located in a different climatic region within the Spanish geographical context. The structures were selected, taking into account the objectives of the design, techniques applied, and location. The study followed a uniform approach for the three structures. It reviewed and analyzed the original authors' documents, as well as any other documentation and opinions published in the media. Each of the case study sites was visited, and one-time on-site measurements of climatic conditions were recorded. In addition, while climatic temperatures were recorded, interviews with people using the space were carried out and observations of people's behavior noted. Measurements were also taken simultaneously in nearby public spaces, in order to compare and assess the strategies used. The analysis of the case studies was divided into two groups: climatic environment—temperature, relative humidity, wind speed, and solar radiation; and the social environment—number of people using the public space and people's perceived comfort. **Table 1** presents the selected case studies, their location, and the strategies used.

Table 1. Case Studies

	Metropol Parasol	Ecobulevar	Plaza Pormetxeta
City	Seville	Madrid	Barakaldo
Project year	2005-2010	2004-2007	2003-2010
Geographic coordinates	37°22′ N, 5°59′ W	40°23′ N, 3°43′ W	43°17′ N, 2°59′ W
Climate	Mediterranean	Continental	Oceanic
Area of the public space	32,605 m2	27,500 m2	27,102 m2
Technique	Canopy, raised plaza, water fountains, low heat storage materials	Solar shields, wind towers, vegetation, light-colored materials	Canopy, wind shields

Figure 1 Pictures of the three case studies. From left to right: Metropol Parasol in Seville, Ecobulevar in Madrid, and Plaza Pormetxeta in Barakaldo.

CASE STUDY 1: METROPOL PARASOL, SEVILLE

Metropol Parasol is located in the historic center of Seville, in a large void of the dense medieval fabric. The structure consists of an extensive canopy of 150 by 70 meters 25 meters above street level, supported by six gigantic columns. The public space that was the object of study, Plaza Mayor, is located underneath the canopy on a platform raised 5 meters above street level. It has a total surface of 10,600 m^2 and is approximately 85 m wide and 140 m long. It is furnished with four concrete semi-circular benches, three small fountains on the borders, and a playground. The materials used are clear granite for the pavement, timber for the canopy, and concrete for the structure, which becomes visible at the bases of the pillars. The purpose of the canopy was to create a comfortable environment in the plaza, where people congregate and big public events take place. The canopy protects the space from direct solar radiation, and the plaza is raised above street level to increase air flow. In addition, the selected light tones of the materials are appropriate for reflecting solar radiation. Moreover, the use of fountains, although scarce, helps to decrease air temperature by evaporative cooling.

The construction work of Metropol Parasol started in 2005 but soon encountered technical problems that forced the construction system to change and delayed its completion to April 2011, also doubling its estimated costs. Considering the current economic crisis that Spain, and especially the region of Andalucía, is going through, the delays and cost overruns of the building have resulted in much public controversy. Nevertheless, the project has been widely published in specialized magazines and journals and generally supported by the professional community, which has awarded the structure with several international prizes of architecture.

Climatic Environment

The main issue when dealing with outdoor comfort in Seville is its high temperatures and solar radiation in summer, which are among the highest in Europe. On July 25, 2012, on-site measurements of temperature, humidity, and wind speed were recorded every hour from 10:00 a.m. to 10:00 p.m. at Plaza Mayor. Simultaneously, on-site measurements were taken at Plaza del Cristo Burgos, a highly vegetated park with two playgrounds located 200 meters west of Metropol Parasol. Temperatures recorded at Plaza del Cristo Burgos were very similar to those at Plaza Mayor between 10:00 a.m. and 1:00 p.m. and between 6:00 p.m. and 10:00 p.m. However, between 2:00 p.m. and 5:00 p.m., when the sun is higher, temperatures were cooler in Plaza del Cristo Burgos. Temperatures in both public spaces were also compared to the climatic data registered at the airport meteorological station. Figure 2a shows the comparison among temperatures in these three points of the city. As shown, temperatures at the airport, located in a non-urbanized area outside of the city, are much lower than in the city during the night, indicating the presence of the Urban Heat Island. In addition, spot temperature measurements were taken at different public spaces across the city, where devices such as canopies were in use to improve pedestrian outdoor comfort. Temperature measurements at these Seville public spaces were taken at different times of the day. Figure 2a shows these measurements as dots to compare them to temperatures at Plaza Mayor. It can be inferred from the graph that Plaza Mayor performed better climatically than most of the other spaces, decreasing temperatures and creating a more comfortable urban environment.

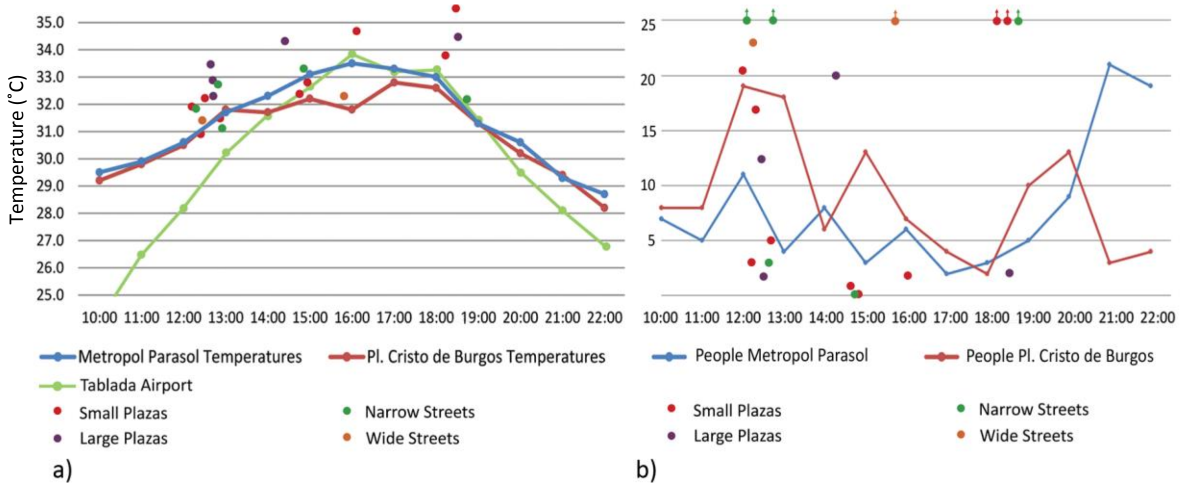


Figure 2 (a) Temperatures measured at Metropol Parasol compared to temperatures measured at other public spaces and (b) People recorded staying at Metropol Parasol and at Plaza del Cristo Burgos.

Social Environment

The number of people present at Plaza Mayor was recorded in parallel to climatic measurements and compared to those at Plaza del Cristo Burgos. As shown in Figure 2b, the number of people at Metropol Parasol was lower than that at Plaza del Cristo Burgos. In addition, Plaza Mayor did not attract as many people as other public spaces of the city where measurements were taken.

A total of 25 interviews were undertaken; questions focused on two topics: the reasons for staying at Plaza Mayor and people's thermal perceptions. Thermal perception was further evaluated by asking interviewees to compare their thermal comfort with the comfort they expected to have in adjacent streets. According to the results, the main reasons for staying at Metropol Parasol were: first, more comfortable climatic conditions; second, attractiveness of the space; and third, the playground. Moreover, all those interviewed found the environment "warm" or "too warm", but most of them stated that the temperature at Plaza Mayor was more comfortable than that in adjacent outdoor spaces. In fact, those who perceived a more comfortable climatic environment were those who nominated the attractiveness of the space as the reason to be there, suggesting an influence of the visual environment on thermal perceptions. All those interviewed had a preconceived idea of Metropol Parasol derived from the exhaustive coverage of the building in the local media as well as in the tourist guides and other city information books. In the case of Seville inhabitants, these preconceived ideas were related to its excessive costs.


a)


b)

Figure 3 (a) Plaza Mayor beneath Metropol Parasol (b) Plaza del Cristo Burgos.

Findings

The climatic techniques applied at Metropol Parasol decreased temperatures by over 3˚C compared to adjacent open areas. When temperatures were compared to those in other public spaces of the city, Plaza Mayor performed better than many, providing a more comfortable climatic environment. Nevertheless, the public space at Metropol Parasol did not draw as many people as other public spaces. Raising the plaza above the street level resulted in more air flow and decreased temperatures. However, the separation of the space from the street, shops, bars, restaurants, and pedestrian and vehicular flows discouraged people from going there. Lack of benches, activities and attractions left the space empty most of the day. In addition, the fieldwork suggested that the powerful visual environment of Metropol Parasol influenced thermal perception. Preconceived ideas, mainly based on economic and political issues, influenced the assessment of the climatic environment. The experience of the thermal environment could not be isolated from issues such as the visual qualities of the structure and its economic and political implications (Nikolopoulou & Steemers, 2003).

CASE STUDY 2: ECOBULEVAR, MADRID

Located in the suburban development of Vallecas in Madrid, Ecobulevar is the redefinition of an existing 550 m by 50 m boulevard according to two objectives: social and environmental. The design team, Ecosistema Urbano, considered trees to be the perfect tools to achieve both objectives (Ecosistema Urbano, 2004). However, according to the project brief, a tree could take 25 years to satisfy these social and climatic needs. Ecosistema Urbano proposed the construction of three artificial trees that would function climatically and socially from the start.

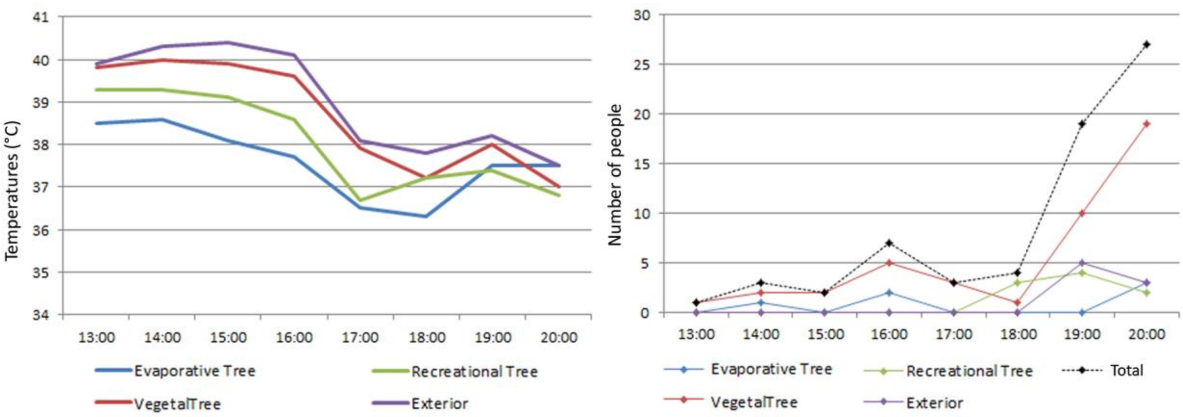
These are composed of cylindrical metallic structures that are around 18 m high with 25 m diameters. Each structure improves climatic conditions using different strategies. The evaporative tree comprises 16 cylindrical wind towers surrounding the principal space formed by a larger cylindrical metallic structure. The wind towers, which are oriented to catch the prevailing winds in the area, inject atomized water to the air flow that passes through them. At the bottom, six nozzles drive the cooled air into the inner space. The second tree, the vegetal tree, is covered by vegetation to provide shadow and decrease temperatures. Finally, the recreational tree is enclosed by an inner screen that, while shading the interior, can be used as a TV screen for different activities. All three trees are located over a modified topography that confines the space and protects it from wind flows.

Climatic Environment

On-site temperature, relative humidity, and wind speed measurements were taken on July 19, 2012 between 12:00 p.m. and 9:00 p.m., both inside and outside the artificial trees. The outdoor temperatures measured on the boulevard that day reached 41 °C, wind flew below 2m/s, and relative humidity levels remained at around 10%. Figure 5a shows the temperatures that were measured inside each tree and at the street hourly. The temperatures remained lower inside the trees than outside them over the course of the visit (see Figure 5a). The greatest differences were found inside the evaporative tree, which is surrounded by 16 wind towers. The maximum temperature difference between the interior of this tree and the outdoor temperature equaled 2.4 °C at 4:00 p.m. On average, the evaporative tree created a thermal environment that was 1.42 °C cooler than outside. The average temperature measured inside the vegetal tree was merely 0.42 °C lower than the exterior temperature, and the highest difference registered was 0.6 °C at 6:00 p.m. The recreational tree presented an average temperature of 1.05 degrees lower than the exterior temperature. The peak in thermal difference was recorded at 4:00 p.m., with an environment that was 1.5 °C cooler inside. Inside the artificial trees, air velocity remained lower than outside, with a maximum value of 1.2m/s, while outside the maximum value recorded was 3.0m/s.

a) b) c)

Figure 4 (a) Evaporative Tree (b) Vegetal Tree and (c) Recreational Tree



a) b)

Figure 5 (a) Temperatures measured inside and outside the artificial trees at Ecobulevar and (b) People recorded staying inside and outside the artificial trees at Ecobulevar.

Social Environment

The number of people staying inside each artificial tree and in the space in between them was recorded in parallel to climatic measurements. Due to the high temperatures that day, the number of people staying outdoors was minimal. Figure 4b shows the number of people staying inside each tree and outside along the boulevard. As seen in the graph, the total number of people increased significantly after 6:00 p.m. and reached its peak at 8:00 p.m., with 27 people or groups of people sitting there. Among the artificial trees, the vegetal tree was preferred. It held more people in five out of the six measurements, with a total of 40 people or groups. The evaporative tree, however, hosted only five people or groups during the six hours of fieldwork and remained empty for most of the time. These measurements contrast radically with the climatic measurements that were recorded, where the evaporative tree provided the most comfortable thermal environment and the vegetal tree the less comfortable. The recreational tree remained vacant until 6pm, but was then used by a total of nine people or groups until 9pm. Similarly, the outdoor spaces between the trees were not occupied until

7pm, when a total of eight people or groups used the seating available there for the next two hours.

In order to understand individual environmental perceptions at Ecobulevar, a total of 25 people were interviewed inside and outside the artificial trees. The interviews followed the same questionnaire as in the previous case study. In this case, the main reasons for staying at Ecobulevar were: first, attractiveness of the space; second, more comfortable climatic conditions; and third, the amenities offered in the space. All of those interviewed found the environment to be "too warm" or "comfortably warm". People inside the artificial trees were asked how temperatures were comparing to outside. 90% of those who liked the artificial trees stated that the climatic conditions inside them were better than outside. Conversely, 75% of people who found the space inside the artificial trees to be unattractive stated that the climatic conditions inside were equal to those outside.

Findings

The fieldwork revealed that the artificial trees did provide a more comfortable thermal environment than that experienced outside of them, but the effects of the strategies varied, depending on the technique applied. Specifically, the evaporative tree was the most effective for decreasing air temperatures and protecting from solar radiation, while the vegetal tree barely modified the existing climatic conditions. However, when the study analyzed the social performance of the artificial trees, the vegetal tree was the most effective. The number of people staying inside the vegetal tree was considerably higher than those inside the other two trees. Based on the conversations and interviews carried out, people chose the vegetal tree for its facilities, specifically the benches and swings. Moreover, the direct connections between its interior and exterior in all directions and without architectural barriers offered a constant visual and physical relation with the outside, which facilitated the access and use of the tree.

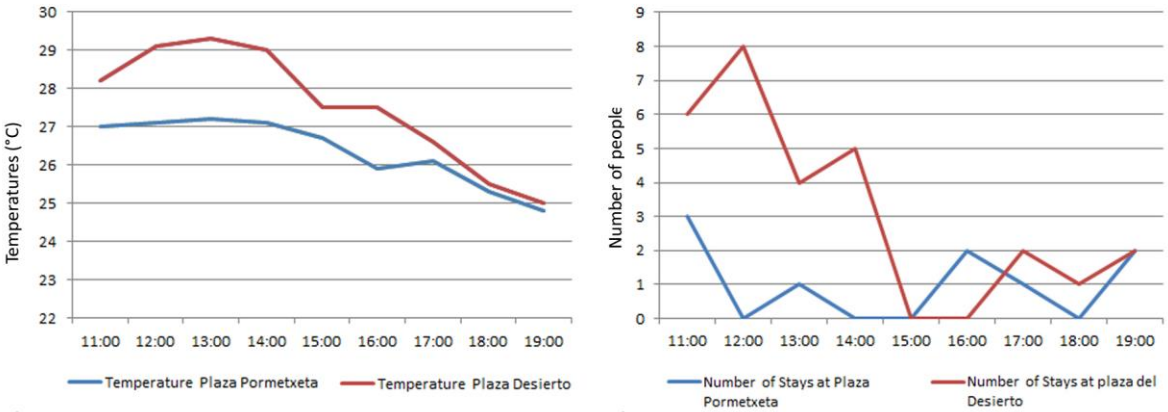
CASE STUDY 3: PLAZA PORMETXETA, BARAKALDO

Plaza Pormetxeta is located in the city of Barakaldo, Spain, which is part of Bilbao's metropolitan area. The plaza connects the town center with the river through a series of walkways that overcome a 20-meter height difference. These walkways are made of steel plates and paved with hexagonal ceramic tiles. At some points, the steel plates fold over the walkways, providing protection from direct solar radiation. The space between the walkways forms a plaza of 6,500 m^2 furnished with benches and playgrounds beneath tree-shaped canopies. This space constitutes the public space object of study, as the tree-shaped canopies aim to create a more comfortable space for citizens by providing shade. The canopies, which are called Stone Trees in the project, cover a 750 m^2 area and are 11.5 meters high. They are constituted by a steel structure of pillars and beams imitating the trunks and branches of a group of trees. On top of the structure, another box structure made of steel holds a metallic mesh and the stones that form the top cover for the canopies. According to the project brief, the Stone Trees "act as an atmospheric device that balances the exuberant natural surroundings" (MTM Arquitectos, 2013).

Climatic Environment

Barakaldo has an oceanic temperate climate with low temperature variations through the year. Summers and winters are both mild seasons with no extreme temperatures. Precipitation is very abundant in Barakaldo, and clouds cover the sky on 330 days per year on average. Moreover, Barakaldo is located in the area with the lowest solar radiation values of Spain, with a mean daily solar global radiation value of 3.54 KWh/ m^2.

On August 21, 2012, on-site measurements of climatic conditions were taken every hour from 11:00 a.m. to 7:00 p.m. beneath one of the Stone Trees. Climatic conditions were unusually warm, with maximum temperatures around 30°C, covered skies, relative humidity levels around 60%, and low wind flows. The maximum temperature recorded beneath the artificial trees was 27.2°C at 1:00 p.m. and the minimum was 24.8 at 7:00 p.m. The maximum humidity level measured was 65.2 at 6:00 p.m. and the minimum was 58.3 at 11:00 a.m. Wind speeds remained similar during the entire measurement period, with maximums around 2 m/sec. These data were compared with climatic measurements registered in Plaza del Desierto, located 150 m from Plaza Pormetxeta. The design for Plaza del Desierto did not consider any strategy for adapting the space to the local microclimate or for generating a more comfortable thermal environment. Figure 6a shows the temperatures measured in both spaces. As shown, temperatures at Plaza Pormetxeta were consistently lower than those in Plaza del Desierto.



a) b)

Figure 6 (a) Temperatures measured hourly at Plaza Pormetxeta and Plaza del Desierto on August 21, 2012 and (b) People recorded staying in both public spaces at the time climatic measurements were recorded.


a) b)

Figure 7 (a) Plaza Pormetxeta (b) Plaza del Desierto

Social Environment

The number of people staying on the plaza, the spaces they occupied, the number of people crossing the space, and the routes they chose were noted. These measurements were recorded simultaneous to climatic measurements. During the nine hours of field study, the total number of stays at Plaza Pormetxeta was 9. Conversely, the number of stays recorded at Plaza del Desierto was significantly higher, reaching 28 by the end of the visit (see Figure 6b). This plaza is surrounded by several cafes, restaurants, and shops that draw citizens to the public space. Although the number of stays in Plaza Pormetxeta was low, it was observed that the number of people that crossed the space was considerably higher. Many people used the pathways to go from the city center to the new urban area by the river and vice versa. But the difficult access to the plaza by labyrinthine pathways and the lack of services and attractions dissuaded people from sitting and remaining there.

Despite the scarce number of people staying under the stone trees at Plaza Pormetxeta, some interviews were carried out to assess the environmental perception of the space. One woman interviewed pointed out that the geometry of the space and the materials used in the construction of the plaza looked dangerous. Specifically, she noted the use of heavy stones suspended on metallic meshes as solar protection as a threatening system that produced an uncomfortable environment. Besides, the enclosed and irregular space formed by the pathways to protect from prevalent winds generated numerous hidden corners and dark spaces, producing a feeling of vulnerability. These statements were also supported by neighbors and the local media (Llamas, 2010).

Findings

On-site measurements proved that Plaza Pormetxeta's canopies and shields decrease temperatures up to 2 ˚C on hot days. However, these elements produced other effects such as darkness and threat that dissuaded people from staying at the plaza. Some residents defined the perceived environment as "dark" and "cold," referring not literally to the thermal environment, but meaning "unfriendly" and "unwelcoming." As a result, the climatic environment generated influenced negatively the built and the social realm. The public space was rarely used and remained empty for most of the time. People stayed in nearby public spaces and used Plaza Pormetxeta as a pedestrian pathway to move through the city but did not stay there. Consequently, Plaza Pormetxeta did not fulfil its role as a public space for the community.

CONCLUSION

Metropol Parasol in Seville decreased temperatures beneath the canopy, providing a more comfortable climatic environment. However, other spaces, such as Plaza del Cristo Burgos, decreased temperatures further with humbler and simpler techniques such as vegetation. In addition, the Metropol space was not used by citizens as much as other nearby plazas due to its lack of social facilities. Ecobulevar in Madrid generated three different microclimates at three points spread along a boulevard, all of them more comfortable environmentally than that found in nearby public spaces. The vegetal tree was the most popular, although it did not provide the most comfortable climatic environment. Finally, Plaza Pormetxeta offered a less comfortable climatic environment, influencing negatively the social environment and discouraging people from remaining there.

The study suggested that, while a comfortable climatic environment is necessary to generate successful urban public spaces, it needs to be combined with other physical and social aspects of the design. The microclimatic environment of a specific urban space has the potential to attract people to or repel people from it. However, it has to be understood as an integrant of the entire design and needs to be treated together with other requirements of the social environment. In fact, the study indicated that the perception of the climatic environment by citizens is not only determined by its physical properties. A further understanding of the socio-cultural and psychological factors influencing outdoor comfort will help producing successful urban public spaces that foster integration and improve quality of life in cities.

ACKNOWLEDGMENTS

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Thermal Comfort in Naturally Ventilated Classrooms

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ABSTRACT

Thermal comfort study is very important because it correlates occupants comfort in built environment to the functioning of the building and energy consumption. PMV-PPD method works fairly well for conditioned buildings. However, this method does not provide expected results when applied to naturally ventilated buildings. Naturally ventilated buildings are much more dynamic compared to conditioned buildings in terms of thermal environment and occupant's behaviour in the built environment. In this study, questionnaire based thermal comfort survey has been carried out in naturally ventilated classrooms of Tezpur University during the months of February and May 2013 i.e. at the end of the winter season and the beginning of summer. Thermal sensation and preferences of 228 students are recorded on ASHRAE thermal sensation scale. Various associated parameters like indoor and outdoor air temperature, humidity, clothing and metabolic rate are also measured. The results reveal that the subjects did not feel extreme levels of thermal discomfort during this period. It has been observed that there is a large variation in the clothing pattern (0.83 to 1.52 clo in winter and 0.43 to 0.68 clo in summer) in both the seasons which justify the behavioural, physiological and psychological adaptation of the respondent. It is also found that the other adaptive means like use of fans, closing or openings of windows etc are used quite often. This study concludes that the comfort temperature range varies from 22 to 23.5 °C in winter month and 27.3 to 30.7 °C in summer month. It also concludes that most of the objects recorded cool thermal sensation and preferred a warmer climate in winter and warm thermal sensation and preferred a cooler environment in summer.

INTRODUCTION

Thermal comfort is defined by ASHRAE as "*state of mind that expresses satisfaction with existing environment*" (ASHRAE 55, 2013). This definition is subjective because state of mind is widely driven by perception as well as expectations of the person in question. It also can be mentioned that the dissatisfaction can be associated with warm or cool sensation of the habitants in general and it is expressed by PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices (Fanger, 1986). Hence, it is not possible to specify an environment that will satisfy everybody's thermal comfort. Considering the discreatness of thermal comfort, it can be stated that the same thermal environment may be perceived differently by different people or different people may perceive same thermal comfort at different thermal environments (ASHRAE 55, 2013). However, it may be possible to specify environments to be predicted acceptable, if at least 80% of the occupants feels comfortable

(Fanger, 1986). At present, the definition of thermal comfort can be approached in two different ways, each one with its own advantages and limitations: the heat-balance approach and the adaptive approach (Singh et al., 2011). The PMV-PPD model (laboratory based) established by Fanger was based on heat balance model (ISO 7730, 2005). The subjects considered in laboratory experiment were European and American students and experiments were conducted in a controlled climate chamber. This method of evaluating comfort is best suitable for conditioned buildings and deviates largely in case of naturally ventilated buildings. The interactions between occupant and immediate environment in a naturally ventilated building are much more dynamic and the occupant's behavioural, physiological and psychological adaptations are more wide compared to conditioned buildings (Alfano et al., 2013; Singh et al., 2011; Singh et al., 2015**)**. Singh *et al.* developed theoretical adaptive thermal comfort models explaining the reason behind the deviation of PMV to that of Actual Mean Vote (AMV) for same set of environmental parameters (Singh et al., 2011). Alfano *et al.* also reported that Fanger's thermal comfort model can be made effective in naturally ventilated environments by adding the right expectancy factor with the model (Alfano et al., 2013).

Wong and Khoo conducted thermal comfort survey in classrooms which are mechanically ventilated by fans in Singapore (Wong and Khoo, 2003). It is found that the occupants' acceptable temperature range lies beyond the comfort zone of ASHRAE standard 55. Corgnati *et al*. carried out surveys in two University classrooms in Turin, Italy applying both objective and subjective surveys confirming that thermal comfort condition and high energy performance are complimentary to each other (Corgnati et al., 2009). Jung *et al.* investigated subjective responses of thermal comfort of students in a University in Korea (Jung et al., 2011) This study found that the mean Thermal Sensation Vote (TSV) of respondents is almost neutral when the PMV in the classroom moves to neutral and slightly cool, and the TSV is almost '+1.5' when the PMV moves to slightly warm. It is also reported in this study that the acceptability ratio of thermal environment is slightly different from ASHRAE Standard 55-2004. It is found from thermal comfort survey at school that children are more sensitive to changes in their metabolism than adults, and their preferred temperature is lower than that predicted by the standard models (Teli et al., 2012; Yun et al., 2014). Wang *et al.* study on thermal environment of University classrooms and offices suggested that the neutral temperature varies with the indoor temperature variations (Wang et al., 2014). This study also concludes that the indoor environment has influences on human adaptability, and this determines different neutral temperatures in winter and spring. Mishra and Ramgopal have done a thermal comfort survey inside a naturally ventilated laboratory in the tropical climatic region of India (Mishra and Ramgopal, 2014). This study found that large number of respondent found their indoor thermal environment to be acceptable. The comfort temperatures obtained in the study are used to develope adaptive comfort equation. This equation shows satisfactory results with the predictions from similar equations in comfort standards. Raja *et al.* studied the use of controls to modify the surrounding environment and how thermal sensation varies with application of these controls (Raja et al., 2001). Pellegrino *et al.* did a small-scale field survey on occupant's comfort and related perceptions in two University buildings in Calcutta, India and found that occupants in naturally ventilated schools show acceptability to a wider range of environmental conditions than specified by ASHRAE and ISO standards (Pellegrino et al., 2012). Hwang *et al.* investigated the adaptive model of thermal comfort for naturally ventilated school buildings in Taiwan and found that the main reason behind discomfort in the classrooms was because most students have to thermally adapt in a naturally ventilated environment when attending school because most of the families in Taiwan have air-conditioners in their household (Hwang et al., 2009).

Thermal comfort assessments of classrooms are important because extreme discomfort conditions may affect the learning ability of students. Since the classrooms thermal environment requirement is completely different to that of residential and office environment, so it demands a separate thermal environment assessment study to be carried out. In this study, thermal comfort survey through questionnaire has been carried out in naturally ventilated classrooms of Tezpur University during the months of February and May 2013 i.e. during the end of the winter season and the beginning of summer.

The thermal sensation and preference of 228 students are taken into account, in terms of the ASHRAE scale and various parameters like indoor and outdoor air temperature, humidity, clothing and metabolic rate are measured. The subjects chosen for this survey were all university students, both male and female belonging to the age group 20 to 26 years. The thermal sensation votes recorded on the ASHRAE 7 point scale during comfort survey is considered as actual mean vote (AMV). These AMV values along with other set of indoor environmental conditions are used to calculate PMV values using ASHRAE 55 and ISO 7730 standard.

METHODOLOGY

Thermal sensation is primarily related to the thermal balance of the body. This balance is influenced by the physical activity and clothing pattern of the habitants. Along with these two variables, the environmental parameters like air temperature, mean radiant temperature, air velocity and relative humidity also has an effect on thermal sensation. Thermal sensation of the occupants can be predicted, if all the above parameters are known. Hence, it is important to find out the response of the occupants about the indoor thermal environment. It has to be kept in mind that judgment of the occupant depends on his perception and expectation about thermal comfort. During field study, questionnaire is administered to subjects and simultaneously other micro-climatic parameters are measured. The subjects were asked to express their level of thermal sensation characterized in ASHRAE thermal sensation scale as shown in Table 1. It is also important to understand that the habitants are always active to the changes in existing thermal environment and always try to adapt themselves to changing environmental conditions to feel thermally comfortable. In naturally ventilated buildings, occupant's preference and expectations about comfortable thermal environment keep on changing with the change in outdoor conditions or seasons (Singh et al., 2010, Singh et al., 2011). During the comfort survey, respondent were advised to sit idle for 20 minutes, and the activity of 1.2 met is considered for the analysis. Clothing insulation is measured in terms of '*clo*' unit, and is used to estimate the insulating properties of clothing by using the tables provided in ISO 7730 standard (ISO 7730, 2005). The clothing value is determined based on an occupant's garment checklist in the questionnaire. Table 2 represents the details of the thermal comfort survey.

Table 1 ASHRAE Thermal sensation scale

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Table 2 Thermal comfort survey details

Climatic zone	Warm and humid
Number of subjects	228 (114 in winter and 114 in summer)
Age group of the subjects	20 – 26 years
Range of clothing (during summer)	0.4 – 0.7 clo
Range of clothing (during winter)	0.8 - 1.5 clo
Number of male respondent	46 (winter); 46 (summer)
Number of female respondent	68 (winter); 68 (summer)

The thermal sensation votes recorded during comfort survey is considered as actual mean vote (AMV). Environmental, activity and clothing level data collected during comfort survey are used to calculate the PMV-PPD by using ISO 7730 standard calculation procedure. The PMV value is calculated by using equation 1 provided in ISO standard (ISO 7730, 2005).

$$PMV = [0.303 \times e^{-0.036 \times M} + 0.028] \times L \quad (1)$$

Where L is the thermal load difference between the internal heat production and the heat loss to the actual environment and M is the metabolic rate. The PPD is calculated by using the equation 2.

$$PPD = 100 - 95 \times e^{-(0.03353 \times PMV^4 + 0.2179 \times PMV^2)} \quad (2)$$

The PMV and PPD results are cross checked using the CBE/Berkley PMV-PPD calculation tool (CBE/Berkley, 2013). PMV values calculated by these methods over estimate the thermal condition in summer season and under estimate the thermal condition in winter season. This may be due to the model fails to consider the adaptive opportunities, preferences and expectations of the habitants in naturally ventilated buildings. It has been tried to use adaptive thermal comfort model which is combination of physics of the body's heat balance plus local climatic behaviour, preference and expectations, past thermal experiences, social and cultural practices to overcome this discrepancy. Hence, it is important to calculate the adaptive coefficient (λ = factor for adaptation) that needs to be added to PMV to make the result close to AMV. Singh et al. 2011 proposed the following relation to calculate the cPMV for naturally ventilated buildings of North-East India.

$$cPMV = \frac{PMV}{1 + \lambda \times PMV} \quad (3)$$

The adaptive coefficient is positive means the indoor temperature is greater than comfort temperature. This case is generally common in summer for naturally ventilated buildings. It also can be concluded that at this situation, the value of cPMV is lower corresponding to the PMV or cPMV is giving cooler feeling than PMV, i.e. cPMV votes are towards comfort to that of same PMV. Similarly, the adaptive coefficient is negative means; the indoor temperature is lower than comfort temperature.This condition occurred in winter season for naturally ventilated buildings. In this situation, it is observed that cPMV is giving warmer feeling than corresponding PMV.

RESULTS AND DISCUSSION

The thermal comfort survey was carried out among the students in naturally ventilated classrooms of six departments of Tezpur University during the months of February and May 2013 i.e. during the end of the winter season and the beginning of summer. The thermal sensation and preference of the students are taken into account, in terms of the ASHRAE 7 point scale. The indoor temperature was in the range 22°C to 23.5°C during Februray and 27.3°C to 30.7°C during May. The indoor humidity during the winter season ranged from 56% to 63% and it was higher in the summer season ranging from 77% to 84%. The outdoor air temperature was found to be slightly higher than the indoor air temperature. It was observed that factors like building orientation and shading affected the indoor temperature.

Clothing level adjustment is one of the important and most effective adaptation processes to maintain the comfort at different temperatures. Figure 1 represents the relationship between outdoor temperature and clothing pattern. It has been found from the comfort survey that the clothing values are largely scattered and varies from 0.43 to 0.68 clo in summer and 0.83 to 1.52 clo in winter. The outdoor temperature variation in winter is from 21.9 to 24 °C and 28.5 to 32°C in summer. It is observed from the Figure 1, that there are two distinct clothing profiles in these two seasons. In summer, the clothing profile decreases, as the outdoor temperature increases and vice versa in the winter season. It can be concluded that there is a strong relation between the clothing pattern and outdoor temperature. The dependence of clothing pattern with the outdoor temperature has been examined through linear and polynomial regression and presented in equation 4 and 5 (where T_0 is the outdoor temperature). The coefficient of regression (CC) is low as this analysis is based on only two seasons of the year.

$$clo = -0.091T_0 + 3.2941 \qquad \text{CC: 0.7449} \qquad (4)$$

$$clo = 0.0081T_0^2 - 0.5253T_0 + 9.0534 \qquad \text{CC: 0.7721} \qquad (5)$$

It is observed that when the clothing level is less than 0.8, the thermal sensation lies from 0 to 2. This shows that during summer when the subject is feeling warm they tend to lessen their clothing insulation to attain comfort. During winter when the temperature is low and the respondent feel cool or cold thermal sensations, the clothing level is high. The respondents wear more clothes to keep themselves warm but in some cases it is observed even though when the temperature is low the students felt warm and the less clothing level is observed. This is justifying the physiological adaptation of the respondent which is resulted from long-term exposure to certain thermal environment which made the respondents habituated. It is found that the CC value is less in the present study than what observed in case of naturally ventilated residential buildings in same climatic zone (Singh et al., 2011). This happens because of restrictions in clothing pattern in University classrooms and sitting positions (sitting near or away from window with varying temperature). However, it can be observed from Figure 1 that the polynomial regression curve bents inwards suggesting the adjustments a subject undergoes and make themselves adapted to reduce discomfort created by high clothing insulation level even at relatively high temperature. This also put forth the argument that in naturally ventilated buildings, the relation between clothing level and outdoor temperature is not linear.

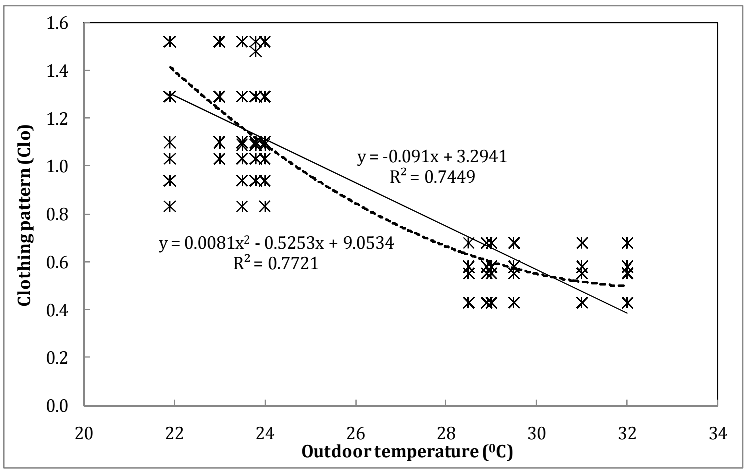

Figure 1 Relationship between outdoor temperature and clothing pattern

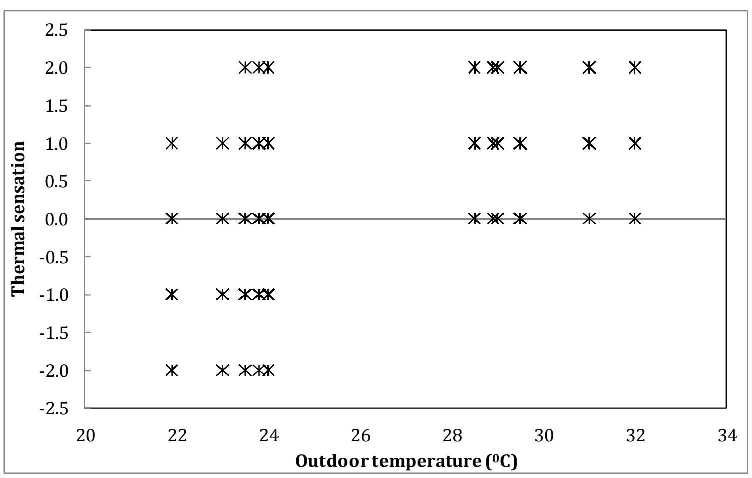

Figure 2 Relationship between outdoor temperature and thermal sensation

Figure 2 represents the thermal sensation profile against outside temperature. It can be observed from the Figure 2 that there are two distinct profiles for two different seasons of the year. In case of winter month, thermal sensation varies from -2 to +2 with the variations of outdoor temperature from 21.9 to 24 °C. Similarly, in summer month, thermal sensation varies from 0 to 2 with the temperature variation from 28.5 to 32 ^{0}C. Perception and expectation about comfort differ from person to person (behavioural, physiological and psychological adaptation). Hence, it can conclude that the same temperature perceived different thermal sensations by the occupants or different occupants perceived same thermal sensation at different temperatures. This also justifies from the clothing level variation in winter and summer months. It is also found from the comfort survey that the AMV is as high as +2 for few respondents. This may be due to the past experiences of cooler thermal environment of these respondents.In this study, inside classrooms the comfort temperature range is found to be 22-23.5 °C in winter and 27.3 -30.7 °C in summer (PMV lies between -1 to 1, or more than 80% of the people satisfied in this temperature range). This comfort temperature range is closely agreed with range of comfort temperature in naturally ventilated buildings reported in different studies (CBE/Berkley, 2013; Hwang et al., 2009; Pellegrino et al., 2012; Raja et al., 2001; Singh et al., 2011).

Predicted Mean Vote (PMV) predicts the mean thermal sensation vote on a standard scale for a large group of people. Predicted Percentage of Dissatisfied (PPD) index provides the number of people dissatisfied at a particular environmental condition. The PMV and PPD values are calculated using the calculation procedure provided at ISO 7730 standard and CBE/Berkley PMV-PPD tool. Figure 3 presents the PMV/PPD values obtained through ISO 7730 (equation 1 and 2) and also by using CBE, Berkley tool. It is observed from the Figure 3, that the PMV-PPD profile complies with the standard PMV-PPD graphs. In this figure, only one side of the profile is observed, as our thermal comfort survey is limited only to two seasons. The experimental results obtained through field measurement (calculated by using equation 1 and 2) are validated by using CBE, Berkley tool. In an attempt to incorporate adaptive comfort model, the PPD upper limit is increased to 20% i.e. -1 to +1 sensation which is completely in agreement with our results at +1 thermal sensation, the PPD value is near to 20 %. It shows that there is a slight variation in PMV/PPD values obtained by these two methods.

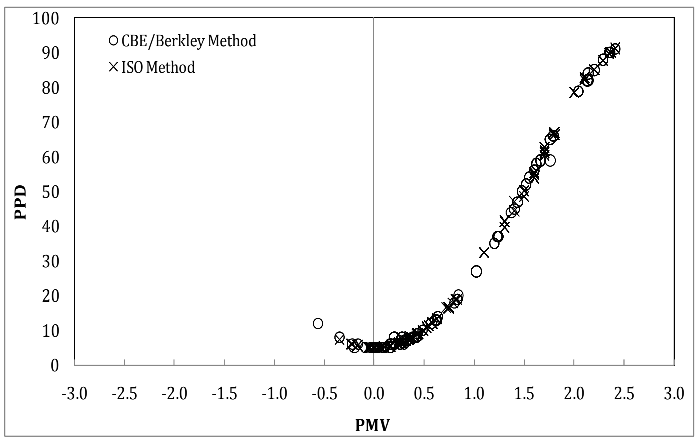

Figure 3 Relationships between PMV and PPD

In case of naturally ventilated buildings, PMV deviates widely from AMV values due to inherent limitation in assessing thermal comfort. To minimize this deviation in PMV values, Singh *et al.* proposed cPMV relation, which accommodates behavioural, physiological and psychological adaptation to calculate the adaptive coefficient (Singh et al., 2011). Equation 3 is used to calculate cPMV values. Figure 4 represents the relation between adaptive mean vote (AMV) and corrected mean vote (cPMV) with respect to PMV. The plot concludes that cPMV provides better indoor thermal sensation as this includes the adaptation of the occupants of a naturally ventilated building. The closer the cPMV to AMV mean it is assessing more correctly the real indoor thermal environment from occupant's perspective. The differences of adaptive coefficients in different seasons present the extent of adaptation of the subject. The adaptive opportunities which are available to the occupants of a naturally ventilated building actually shift the neutral temperature as well as the range of comfort temperature. It is observed from the Figure 4 that the cPMV values (-1.32 to 1.45) come closer to AMV values (-2 to +2) whereas PMV values are distributed between -1 to 3. This adaptation processes through different adaptive opportunities help the respondent to achieve required thermal comfort at a relatively lower indoor temperature in winter or higher temperature in summer month.The positive adaptive coefficient means the corrected mean vote is giving cooler feeling than the predicted mean vote. This kind of situation would occur in warm months, when the indoor temperature is higher than the comfort temperature. The reverse situation would also occur for winter months.

The thermal comfort survey has been carried out to the University students of both male and female in the age group 20 to 26. It is important to note that the age of respondent does not have any signification variations on the thermal sensation. However, as the comfort survey has been done only for two seasons, it will not be wise to make any generalized comment on this. The outdoor temperature variations during the winter days of the survey were 21.9 to 24 °C. Most of the subjects recorded cool thermal sensation and preferred a warmer climate. However, 25% voted in the neutral range and it is observed that a few subjects felt warm thermal sensation in this temperature range. Thermal comfort survey during the summer, the outdoor temperature variations recorded was 28.5 to 32 °C. Most of the subjects voted +1 or +2 i.e. slightly warm and warm thermal sensation and preferred a cooler environment. It is also observed that there is a drop of *clo* value as the temperature increase in summer months in comparison to winter months. Change in clothing pattern is a significant adaptive measure adopted by the students to increase their level of comfort. The students increase or decrease their layers of clothing in winter and summer respectively to adjust with the environment.

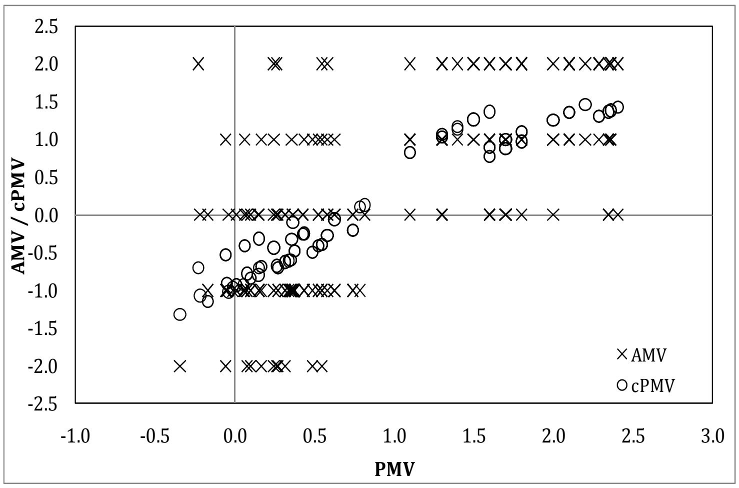

Figure 4 Relationship between PMV, AMV and cPMV

The thermal comfort temperature recommended by ASHRAE and obtained from the survey is presented in Table 3. Ranges of comfort temperature are derived from the comfort survey and corresponding measurements that were carried out during survey. The range of temperature represents the temperature corresponding to thermal sensation -1 to +1 (according to adaptive thermal comfort model, occupants can make themselves comfortable in this range by utilizing adaptive opportunities in naturally ventilated buildings). It is observed from Table 3 that the acceptable limit of comfort temperature recommended by ASHRAE is closely similar to the survey results for winter months. However, the summer months acceptable limit does not agree with the ASHRAE recommended value. This can be due to limited respondent and also for only two seasons have been covered in the thermal comfort survey. It is highly desirable that the thermal comfort survey to be done throughout the year with more respondent to get the generalized comfort temperature range.

Table 3 Comfort temperature recommended by ASHRAE and obtained from survey

Conditions	ASHRAE recommended acceptable operating temperature (°C)	Comfort temperature obtained from survey (°C)
Summer (light clothing)	Humidity range if 30% : 24.5 – 28.0 Humidity range if 60% : 23.0 - 25.5	Humidity (%) : 77 - 82.2: 27.3-30.7°C
Winter (warm clothing)	Humidity range if 30%: 20.5 - 25.5 Humidity range if 30%: 20.0– 24.0	Humidity (%) : 55 - 63: 22-23.5 °C

CONCLUSION

This study is based on the responses of the questionnaire based thermal comfort survey of 228 students of Tezpur University. The survey was carried out in six naturally ventilated classrooms at various departments located inside the University. The survey has been carried out during two different seasons of the year. It has been found that adaptation of the respondents is clearly visible in the clothing pattern which has a strong dependence on outdoor temperature. The comfortale thermal sensation (acceptable) has been observed for the temperature range from 22 to 23.5 °C in winter and 27.3 to 30.7 °C in summer month. Clothing level varies from 0.83 to 1.52 clo in winter and 0.43 to 0.68 clo in summer month. Most of the subjects recorded cool thermal sensation and preferred a warmer climate in winter. Most of the subjects voted +1 or +2 i.e. slightly warm and warm thermal sensation and preferred a cooler environment in summer. It is observed from the comfort survey that clothing pattern is a significant adaptive measure adopted by the students to increase their level of comfort. It can be concluded that the deviation in AMV to that of corresponding PMV is due to various adaptation processes used by the students to make themselves comfortable in the indoor environment. Different values of adaptive coefficient provide a better understanding about the impact of various adaptive factors on an individual to attain thermal comfort. It is felt that thermal comfort survey should be done throughout the year with more respondent to get the generalized comfort temperature range.

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Comparison of Strategies improving Local Energy Self-sufficiency at Neighborhood Scale. Case study in Yverdon-les-Bains (Switzerland)

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ABSTRACT

Within a context of growing efforts to develop sustainability strategies, one of the main challenges is promoting value creation while using fewer resources. In this perspective, how can we design attractive urban neighborhoods generating endogenous economic activity and fostering socio-cultural dynamics, while moving towards local energy self-sufficiency? Answering that question requires major changes in the way we consider energy in the construction sector, by thinking beyond the scale of a single building and by including a greater number of design parameters. Filling this gap in current research, the Symbiotic Districts project examines dimensions influencing energy self-sufficiency at neighborhood scale by integrating parameters related to buildings, infrastructure, mobility, food, goods and services.

The present paper analyzes the results of a case study on an urban sector in the city of Yverdon-les-Bains (Switzerland). Taking lifestyles as a starting point, the project explores three scenarios (technological, behavioral and symbiotic) for the future development of this neighborhood for 2035. The scenarios test different design strategies related to industrial symbioses, production, storage, transportation or urban agriculture. In order to calculate an estimated global balance, an energy flow analysis allows the assessment and comparison of the energy performance of each scenario. In parallel, an urban form adapted to the proposed vision evaluates how architectural and urban design is likely to foster the necessary behavior changes towards the expected energy turnaround.

1 INTRODUCTION

Within a context of a growing efforts to create sustainable development strategies, a wide array of research programs are being conducted on energy-related issues in the built environment. And for good reason: over 40% of worldwide energy consumption can be attributed to the construction sector (Wallbaum, 2012). In Switzerland, a landscape dense with urban development, total energy expenditures associated with buildings account for no less than half of total energy consumption (Zimmermann, Althaus, & Haas, 2005). Ambitious objectives to reduce renewable and non-renewable energy consumption are now being set by several European countries, following the example of the 2000-Watt Society concept developed in Switzerland or the political vision of phasing out nuclear energy over the medium-term (Jochem, 2004; Previdoli, 2012).

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At the same time, the projected end of abundant low-cost fossil fuels, geopolitical tensions around the issue of natural resources and the vulnerability of electrical power grids are all factors that encourage finding more secure energy supply strategies, particularly by making use of local resources. With this objective in mind, working towards local energy self-sufficiency – and specifically a balance between the energy consumption of a territory and its ability to meet its own demand through sustainable production – will allow us to minimize environmental impacts while at the same time generating endogenous economic activity and promoting a social and cultural dynamic in which the users can become involved. This type of approach requires a significant reduction in demand (moderation), the widespread use of renewable energy (local production), and an effort to achieve complementarities between operation (industrial symbiosis) and on-site energy storage (Grospart, 2009).

Taking these matters into account requires major changes in the way we consider energy in the construction sector, firstly by clearly transcending the scale of the single building in order to address urban reality at neighborhood scale (Rey, Lufkin, Renaud, & Perret, 2013). This intermediate scale reveals some surprising information. On one hand, it is broad enough to address themes that transcend the single building, opening up possibilities for studying interactions between these entities. On the other hand, unlike city scale, on which most of the current research on local energy self-sufficiency focuses, it is restricted enough to design, test and examine concrete and operational initiatives (Rey, 2011). Therefore, this approach allows taking into account multi-functionality, considering certain industrial activities and urban or suburban agriculture activities near residential areas, while keeping them to the appropriate scale for the most strategic approaches to urban development (e.g. master plan).

Secondly, a greater number of design parameters needs to be included in the reflection, moving well beyond basic issues related to the buildings' heat and electricity consumption. The observation of the traditional neighborhood highlights the limitations of its urban flows operational scheme. This urban metabolism, which can be described as linear, requires large amounts of external inputs, largely stemming from non-renewable sources, and generates a high level of non-valorized rejects (waste, greenhouse gas, dissemination into the environment or liquid effluents). In addition, interactions between the functions are very limited. This system increases the neighborhood's ecological footprint and could potentially challenge its very existence over the long term.

To work towards greater sustainability, new modalities are therefore needed to increase both the self-sufficiency and efficiency of urban environments. In reaction, the Symbiotic District project was conceived in order to promote a "syntropic" urban system, i.e. a mature ecosystem capable of fostering cities' economic and sociocultural development, while making the best use of imported resources and limiting waste production thanks to a circular metabolism. Concretely, such an approach embraces industrial ecology principles (Erkman, 1998) and aims at transposing them to the built environment in general, and the Swiss urban context in particular. The Symbiotic District project simultaneously examines scientific, technical, urban development and architectural aspects of local energy self-sufficiency at neighbourhood scale by integrating issues related to buildings, infrastructure, mobility, goods, services and food (Lufkin, Rey, & Erkman, 2014). The approach relies on three complementary optimization strategies: increasing the city's intrinsic efficiency, valorizing renewable energy sources and implementing urban symbioses (Lufkin, Rey, & Erkman, 2013).

The research also aims at identifying the most relevant levers to reduce energy consumption - lifestyles, technology or urban form - and studying interactions between these lines of action. Indeed, in spite of increased consciousness about energy issues, private or public stakeholders find it difficult to commit to a responsible behavior due to the absence of sufficiently accurate information. Establishing a reliable basis to address energy issues in future sustainable urban neighborhoods (in the horizon 2035), the approach provides a systematic exploration of the links, still to be created, between strictly quantitative aspects related to energy self-sufficiency (stemming from industrial ecology) and qualitative and operational aspects related to their implementation into urban and architectural projects (Erkman, 1998).

2 STATE OF THE ART

The idea of considering city as an ecosystem is not new. It was introduced in the sixties, in particular by biologists, who started drawing their inspiration from the theory of ecosystems in order to deal with the complexity of the environment and to understand it in a more systematic way. Deriving from these reflections, urban metabolism provides sound methodological and practical tools to analyze urban resources and flows (Baccini, 1996; Newman, 1999). Applying this approach to cities, researchers started highlighting a number of dysfunctions: high dependency towards fossil energy, low efficiency due to linear processes, inefficiency of sectoral policies and "end of pipe" solutions, etc. (Barles, 2008; Dobbelsteen, Keeffee, Tillie, & Roggema, 2012). Urban metabolism is a very efficient approach to assess a region's or a city's level of sustainability and to identify resources and waste potentially re-usable at regional scale (Codoban & Kennedy, 2008). However, territorial or urban scale remains too large to transpose the results from such a model to strategic operational processes.

To date, attempts to apply urban metabolism at neighborhood scale are few and very recent. Indeed, the parameters usually considered in research and practice rarely go beyond the building's energy consumption (heating, domestic hot water, electricity, grey energy). A limited number of experiences try to include aspects related to the inhabitants' transportation and food in a broad perspective, addressing energy supply as both an energy consideration – power supply accounts for a significant portion of the total energy balance per inhabitant (Rey, 2006) – and from an urban development standpoint – urban agriculture, for instance, is becoming an increasingly popular consideration with regard to achieving urban sustainability (Gorgolewski, Komisar, & Nasr, 2011; Jourdan & Mirenowicz, 2011).

These examples include the REAP methodology in Rotterdam (Tillie et al., 2009), the Amsterdam Guide to Energetic Urban Planning (Tillie, Kürschner, Mantel, & Hackvoort, 2011), the Urban Harvest Concept in Kerkade West (Agudelo-Vera, Leduc, Mels, & Rijnaarts, 2012) and the New Stepped Strategy (Dobbelsteen, 2008). These references speak to the benefits of combining different functions within the same neighborhood or even within the same building, thus revisiting a "fine-grained" functional mix. All these pilot projects are still at experimentation or planning phases, none of them has yet been realized. Today, the main challenge is their integration into a consistent and realistic reflection in order to positively influence local energy and resource self-sufficiency at neighborhood scale.

3 METHODOLOGY

In reaction, the case study presented in this paper focuses on the Gare-Lac sector in Yverdon-les-Bains (Switzerland). The site is currently a large urban wasteland of about 23 hectares, strategically situated between the railway tracks and Lake Neuchâtel, in very close proximity to the station and the city center. The local master plan (PDL) (Bauart Architectes et Urbanistes SA, 2010), currently under validation, was used as a basis for the present case study. The research is conducted in four stages:

1 - Energy cadaster Making an inventory of available local resources, the first stage establishes a regional energy cadaster. Renewable energy production installations and supply projects situated within the perimeter of the urban region of Yverdon are listed. The resulting local energy mapping takes into consideration resources such as biomass, sun, wind, waste heat, geothermal potential, lake, etc.

2 - Scenarios Based on this cadaster and on the recent PDL, three radical scenarios (technological, behavioral and symbiotic) are developed in a 2035 perspective. Enriched by prospective reflections on the evolution of European lifestyles (IDDRI, 2012), the scenarios embody a specific positioning to meet sustainability concerns. Set by the PDL, the human density (number of inhabitants and jobs per hectare) is the same for all scenarios, i.e. 3'810 inhabitants and 1'260 jobs. The built density (gross floor area, GFA), however, varies from one scenario to the other, mainly because of the variation of average per capita living space and the type of activity.

3 - Energy flow analyses For each scenario, several hypotheses are then formulated. They are structured into five domains, which contain a variable number of categories and sub-categories:

Table 1. Summary List of the five domains and their respective categories

Buildings	Mobility	Infrastructure	Food	Goods and services
Construction	Car	Neighborhood /	Agriculture	Clothes
Domestic hot water	Airplane	municipal facilities	Transformation	Furniture
Heating/Ventilation	Train	External installations	Packaging	Restaurant
Lights and devices	Other	Other	Distribution	Hotel / Leisure

Three indicators are calculated in order to analyze the energy consumption of each scenario: Total Primary Energy (TPE), Non-renewable Primary Energy (NRPE) and Global Warming Potential (GWP). The first step is the evaluation of the current situation, which serves as reference point. Users behavior and habits are based on the current Swiss average. Each (sub)-category value is then adapted according to the scenario's specific hypotheses.

4 - Urban form In parallel, an urban form is proposed for each scenario (Fig. 1-3). It is developed according to the lifestyle assumptions on which the scenario is based and provides a visualization of the future neighborhood. Indeed, each lifestyle reflects distinct uses, which correspond to specific needs in terms of spatial, functional and sensitive qualities (Thomas, 2011). This transposition of conceptual assumptions into an urban form also assesses the extent to which urban and architectural quality is likely to promote behavioral changes necessary for a transition towards a more sustainable society.

4 RESULTS

4.1 Local resources

The identified local resources are attributed to the Gare-Lac neighborhood according to a principle of territorial representativeness. For instance, if a resource is shared by the whole urban region (or the city) of Yverdon-les-Bains, only 7% (respectively 14%) of this potential is allocated to the site. This percentage corresponds to the ratio between the site's population and that of the considered territory.

Waste heat The public baths of Yverdon, whose water is heated to 32°C, and the water treatment plant are the major installations likely to contribute to local symbioses through a process of waste heat recovery. The combination of these two sources could potentially produce 3.5 thermal MW. Due to the proximity of these installations to the site, it was decided to allocate 30% of this potential to the new neighborhood.

Geothermal potential According to information provided by the Commune of Yverdon-les-Bains, a geothermal cogeneration project should be completed in 2017. It represents a potential of 5 electric MW and 60 thermal MW, of which 14% are allotted to the new neighborhood.

Biomass It was estimated that organic waste produced by the inhabitants of the neighborhood and the animals living in the vicinity could produce as much as 114 electric kW thanks to heat-power coupling generated by agriculture biogas. In addition, a wood-energy plant is being studied. The latter could potentially produce 17 thermal MW, of which 14% would be allotted to the Gare-Lac sector.

Solar potential The SEY have planned a photovoltaic supply growth of 0.5 MW per year until 2035, i.e. a total growth of 13 MW including the existing capacity. In a similar way as biomass and geothermal potential, 14% of the stock is attributed to the future neighborhood.

Wind potential Two major wind power projects are being considered in the Northern Vaud region, totaling 39.5 electrical MW. Considering this scale, only 7 % of this energy will be distributed to the neighborhood, i.e. 2.8 electric MW.

Lake Neuchâtel In spite of the important potential of the lake, it has not been considered as a thermal resource for the sake of realism. For environmental reasons, this option is not desired by cantonal and communal authorities of the urban region of Yverdon-les-Bains.

The following table provides a summary of the available local resources, which are then allocated to the future neighborhood according to the hypotheses formulated by each scenario:

Table 2. Summary List of the local resources available

Resource	Waste heat	Geothermal	Biomass	Sun	Wind
Thermal [MW]	3.5	60	17	-	-
Electric [MW]	-	5	0.1	13	39.5
Percentage attributed to site	30 %	14 %	14 %	14 %	7 %

4.2 Performance of the scenarios

Technologic scenario Using the most advanced technologies to reduce energy consumption, this scenario doesn't imply any modification of the user's behavior. Overall, the environmental impacts decrease thanks to the improvement of the devices' efficiency, but this effect is counterbalanced by the general higher consumption. Main characteristics of this scenario are: Minergie A standard for all buildings, heavy construction mode, integration of renewable energies, increased average per capita living space (60 m2 per person instead of the current 50 m2), stabilization of travelled kilometers, hydrogen-powered cars (for 50% of the users), imported, transformed and conditioned food, etc.

Table 3. Synthetic chart of the performance of the technologic scenario

Domain	TPE [W/pers]	NRPE [W/pers]	GWP [kg CO2eq/year]
Buildings	642	428	914
Mobility	2'299	1'199	2'238
Infrastructure	551	491	603
Food	720	663	1'638
Goods and services	750	690	1'012
Total	**4'962**	**3'471**	**6'405**

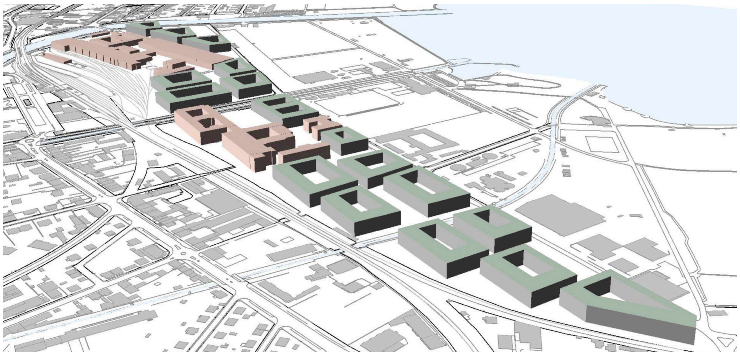

Figure 1 Visualization of the technologic scenario. Roofs' volumetries have been optimized in order to integrate photovoltaic panels (in green).

- Inhabitants: 3'810;
- Jobs: 1'260
- GFA: 260'100 m^2

Behavioral scenario This scenario takes the opposite view and relies mainly on a change in users' behavior towards more frugal consumption, sobriety, simplicity, reduced consumerism and decelerating lifestyles. Thus, the driving force of the energy transition is mostly the demand reduction thanks to the modification of current social practices (energy supply by biogas and wood-energy plant, light wooden constructions, pooling of facilities, diminution of the average per capita living space to 40m2 per person, increased soft mobility, increased car occupancy through car sharing, urban farming, natural treatment for public spaces, vegetarian, local and organic diets, autonomous production of goods and services, etc.)

Table 4. Synthetic chart of the performance of the behavioral scenario

Domain	TPE [W/pers]	NRPE [W/pers]	GWP [kg CO2eq/year]
Buildings	651	449	400
Mobility	1'483	1'353	2'515
Infrastructure	508	479	578
Food	406	373	923
Goods and services	638	587	860
Total	**3'685**	**3'240**	**5'275**

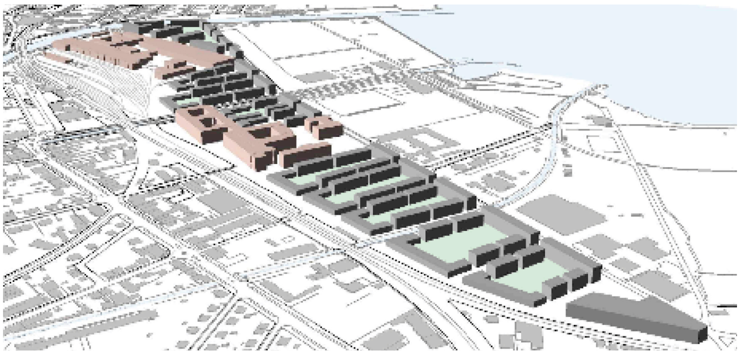

Figure 2 Visualization of the behavioral scenario. Large garden dedicated to urban farming are also special meeting places for the inhabitants (in green).

- Inhabitants: 3'810;
- Jobs: 1’260;
- GFA: 209’100 m^2

Symbiotic scenario This scenario promotes urban and industrial symbioses opportunities to reduce the environmental impact of the neighborhood. Energy exchanges are implemented at all scales (building, group of buildings, neighborhood and between the neighborhood and its surrounding perimeter). The symbiotic scenario implies changes in behavior, but not as radical as the ones required by the behavioral scenario: users take responsibility toward sustainability and foster network and partnership dynamics. The main features of this scenario include: energy mainly supplied by heat recovered from the public baths and water treatment plant (3,4 thermal [MW] and 0.1 electrical [MW]), Minergie P standard for new constructions, recycled materials, heat recovery on waste domestic water and ventilation, stabilization of the average per capita living space (50m2 per person), significant functional diversity (crafts and non-polluting industries), smaller and lighter vehicles, biodiesel for cars, development of the public transport network, diminution of air travels, healthy and responsible diet (reduced meat consumption, local and seasonal products), recyclable or repairable goods).

Table 5. Synthetic chart of the performance of the symbiotic scenario

Domain	TPE [W/pers]	NRPE [W/pers]	GWP [kg CO2eq/year]
Buildings	778	690	731
Mobility	1’307	1'187	2'015
Infrastructure	543	513	611
Food	653	600	1'485
Goods and services	675	621	911
Total	**4'005**	**3'654**	**5'775**

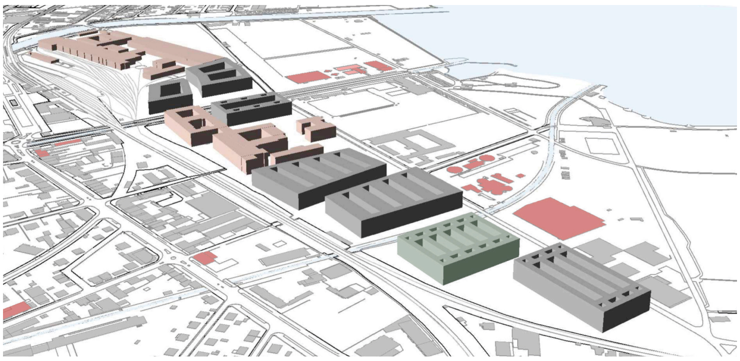

Figure 3 Visualization of the symbiotic scenario. Large urban blocks encourage short-distance exchanges at building and neighborhood scale.

- Inhabitants: 3'810;
- Jobs: 1’260;
- GFA: 262’320 m^2

4.3 Discussion of the results

First of all, the energy consumption of all three scenarios is lower than that of the current situation (Figure 4). Besides, the ranking is rather immediate: for all indicators, the behavioral scenario appears as the most performing, and the technologic scenario is the most energy intensive (except for NRPE). However, these results need to be contrasted with the fact that only energy-related aspects were integrated into the assessment. Other criteria, in relation to social (acceptance), economic (costs of the implemented technologies) or environmental impacts, would be necessary in order to establish a more complete and global evaluation of the scenarios. For instance, the radical and very restrictive vision embodied by the behavioral scenario is not fully realistic because of all the constraints imposed on the inhabitants' individual freedom. This remark highlights the relevance of holistic approaches, which form the core concept of sustainable development.

Nevertheless, the three indicators bring to light certain interesting phenomena. Concerning buildings, for instance, results are counter-intuitive: the buildings with the lowest energy consumption – those of the behavioral scenario – comply with the least strict construction standard. The explanation is provided by two factors: the average per capita living space and the construction modes. In the behavioral scenario, the reduction of living space to 40 m2 per person (compared to the current 50 m2) leads to a diminution of approx. 30% of the necessary GFA in the neighborhood, which significantly influences construction and operation energy. In addition, light wooden constructions have a positive impact on the buildings' grey energy (as opposed to the heavy constructions of the technologic scenario).

Mobility also plays an important role in the energy balance of the scenarios. In the technologic scenario, mobility represents approximately half of the TPE. Its impact decreases a lot for the NRPE, thanks to the use of hydrogen-powered cars. In the behavioral scenario, the use of conventional cars penalizes the balance in spite of the absolute reduction of kilometers travelled. The symbiotic scenario offers the most convincing solution by encouraging simultaneously the use of collective transports and of biodiesel and electric cars (produced from renewable sources).

Regarding food, the most significant levers are related to reduced meat consumption. However, the impact of this change of eating behavior on the global balance remains low. From a strictly energetic point of view, this effort is of minimal benefit while a transition towards a vegetarian diet implies a high level of commitment of the inhabitants.

5 CONCLUSIONS AND FUTURE PERSPECTIVES

In order to put this reflection in perspective with long-term sustainability objectives pursued by several countries, Switzerland in particular, the results were confronted to the intermediary goals of the 2'000 Watts society concept for 2035 (Jochem, 2004). Figure 4 shows that none of the radical scenarios meets the targets for all three indicators. TPE values of both the behavioral and symbiotic scenarios are below the threshold of 4'400 [W/pers], while the technologic vision exceeds the limit. For NRPE, results of the three scenarios are all slightly above the objective of 3'300 [W/pers]. However, considering the uncertainties affecting some of the data, it can be considered that these orders of magnitude are roughly equivalent. CO2 emissions of the three scenarios, by contrast, clearly exceed the intermediary target of 3,2 [tons CO2eq/year]. This can be explained in part by the pessimism of the assumptions on which calculations of the flow analyses were made. In the next few years, technological innovations can be expected to improve efficiency and reduce losses of the systems. In relative terms, greenhouse gases emissions should therefore decrease more than absolute fuel consumption. However, these complex developments are difficult to forecast and would require a more in-depth analysis, which goes beyond the scope of the present research.

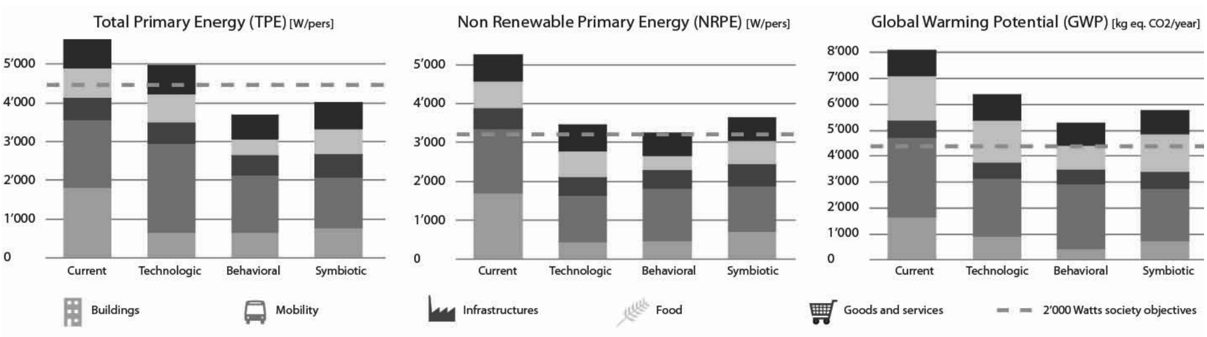

Figure 4 Histograms showing the comparative results of the current situation and the three scenarios, as well as the confrontation to the 2'000 Watts society objectives.

This confrontation to the 2'000 Watts society targets illustrates that no single strategy can work on its own to move societies towards a global energy transition. The behavioral scenario, which appears at first view as the better candidate, raises a series of questions in terms of acceptance and future oppositions. The energy consumption of the technologic scenario remains too high – not to speak about unresolved problems of economic feasibility. The same doubts can be expressed with respect to the symbiotic scenario, which would require intense political backing and educational support in order to translate the opportunities offered by urban symbioses into real achievements. Accordingly, a balance needs to be achieved by merging these strategies. It is precisely the objective of the future stages of the present research, which will explore this middle way approach by developing integrated scenarios, combining technological innovation, changes of lifestyle and short-distance exchanges.

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Session 1D : Tools and methods/ framework

PLEA2014: Day 1, Tuesday, December 16
11:30 - 13:10, Trust - Knowledge Consortium of Gujarat

PROSOLIS: a Web Tool for Thermal and Daylight Characteristics Comparison of Glazing Complexes

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ABSTRACT

Since these last years, the application of the European Energy Performance Building Directive (EPBD) has led to a higher interest in summer comfort issue. In this context, the design of glazing complexes (glazing and solar shading) is a key issue since it directly influences the thermal and visual perception of interior spaces. Glazing complex determine the view and the opening to the outside, determining solar gains and penetration of natural light, but is also responsible for heat loss and can cause overheating and glare. The choice of an adequate glazing complex should therefore be done considering all of these aspects.

This paper presents a free web tool realised within the frame of the PROSOLIS research project. Based on a set of results obtained by the advanced use of BSDF functions for optical properties description of solar shading in specific thermal and daylight simulation software's (WINDOW 7, EnergyPlus 8, Light-tools 8.0), the PROSOLIS web tool helps to evaluate the impact of the glazing complex choice on both thermal and visual comforts in residential and office buildings.

This web tool, dedicated to building designers, proposes a multi-criteria approach for comparing accurately the most current types of glazing complexes. It considers internal and external screen fabrics and venetian blinds, combined with five different types of glazing and informs designers on energy and light performance levels of the selected combinations. From this information, designer should be able to easily choose glazing complexes fitting with their needs.

INTRODUCTION

PROSOLIS is a tool designed to compare the energy and light performance levels of different glazing and solar shading combinations. Users can therefore study and compare the behaviour of different combinations of glazing and of solar shading parallel to glazing for a wide range of configurations depending on the position of the solar shading, window orientation and use of the studied building.

The tool is divided into 6 main screens: *use*, *orientation*, *glazing*, *solar shading*, *concise and detailed results*. It also integrates a word index defining all technical terms used in the tool. The help section shows how to use the tool and presents the hypothesis on which the simulations are based. The tool is available in French and English on *www.prosolis.be*.

USE SELECTION

In the first screen of the tool, the user can choose from three room types: *living room (residential building), sleeping room (residential building) and individual office space (non residential building)*. This choice determines the simulation conditions and hypotheses behind the contextualized energy property results (*cooling needs of the room, heat balance of the complex (see after)*).

To provide valid thermal behaviour, two whole buildings have been modeled (Figure 1): one residential building and one office building. Both models include 13 thermal zones. The first covers all everyday functions of a single-family home (kitchen, sleeping room, living room, washroom, etc.) and the second covers those of an office building (office space, corridors, etc.). All thermal simulation hypothesis regarding geometry, construction types, internal gains, hours of occupancy are described in the help section of the tool.

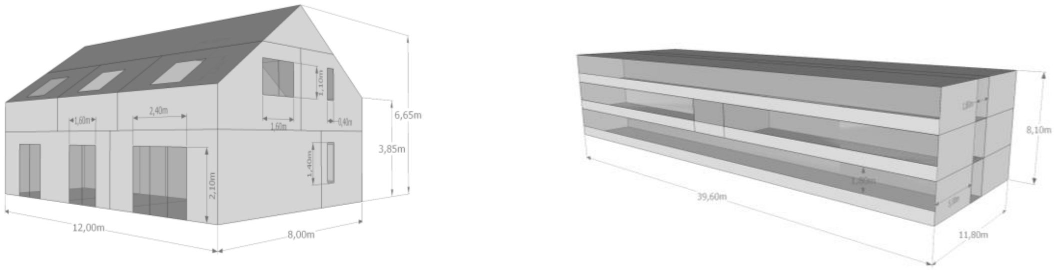


Figure 1 Thermal modellings. Left: residential building - Right: office building

ORIENTATION SELECTION

The user can choose among eight different orientations *(North, North-East, East, South-East, South, South-West, West and North-West)* determining the conditions for the room being studied.

GLAZING SELECTION

Five different types of glazing (presented in Table 1) are proposed: *clear double glazing; clear double solar control glazing; double glazing with enhanced solar control; reflecting double glazing; triple glazing.*

Table 1. Properties of glazing

		Clear double glazing	**Clear double solar control glazing**	**Double with enhanced solar control**	**Reflecting double glazing**	**Triple glazing**
Energy properties						
Thermal transmittance factor	Ug [W/m²K]	1.2	1.1	1.1	1.0	0.7
Solar factor	g [-]	0.62	0.41	0.35	0.30	0.60
Solar transmittance	τ_e[%]	53	37	31	27	53
Solar reflectance	ρ_e [%]	23	28	32	33	25
Solar absorption	α_e [%]	24	35	37	40	23
Light properties						
Light transmittance	τ_v [%]	77	69	61	50	72
Colour rendering index	Ra [%]	98	97	95	97	99

SOLAR SHADING SELECTION

As presented in Figure 2, the user can specify: *the potential absence of solar shading*; *the position of the solar shading: interior or exterior*; *the type of solar shading: blinds or screens*; *the properties of* *the selected solar shading (optical properties, tint, fabrics type, etc.)*. For screens, the user can choose among 6 screens of different colours (black, grey, white) and fabric types (natte or serge). For blinds, the user can choose among 4 slats of different colours (dark or light grey) and reflexion types (diffuse or specular). The solar shading devices were selected to represent the products found in practice for standard solar shading applications. Their properties are presented in Table 2 for screens and in Table 3 for venetian blinds. For blinds with metal slats, the slats are fixed and inclined at a 30°angle in relation to the horizontal position.

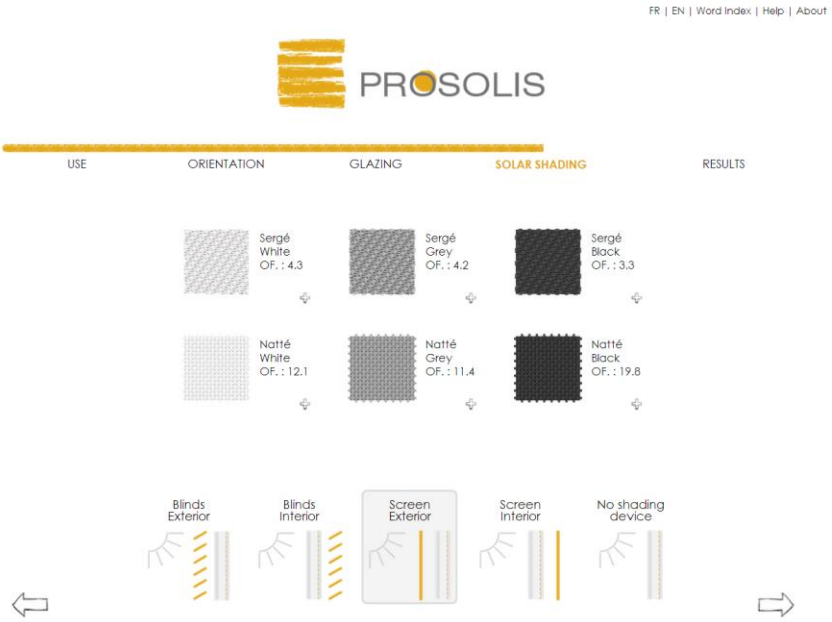


Figure 2 Screen for shading device selection

Table 2. Properties of screens

		Serge White	Serge Grey	Serge Black	Natte White	Natte Grey
Energy properties						
Solar transmittance	τ_e [%]	20.5	7.1	3.7	27.1	15.1
Solar reflectance	ρ_e[%]	66.5	19.0	5.9	61.6	19.0
Light properties						
Light transmittance	τ_v[%]	19.9	5.4	3.7	26.4	13.1
Other properties						
Openness factor	O.F. [%]	4.3	4.2	3.3	12.1	11.4

Table 3. Properties of slats

		Diffuse reflection Light grey	Specular reflection Light grey	Diffuse reflection Dark grey	Specular reflection Dark grey
Energy properties					
Solar reflectance	$\rho_{e,n-h}$ [%]	52.7	58.8	20.8	39.0
Light reflectance	$\rho_{v,n-h}$ [%]	59.2	59.4	21.1	44.5
Light properties					
Light transmittance	τ_v[%]	0.0	0.0	0.0	0.0

CONCISE RESULTS

This section of the tool allows users to easily compare the behaviour of different glazing complexes (up to four) for the following criteria: *Overheating protection*; *Daylight harvesting*; *Glare protection*.

Overheating protection

This criterion compares the efficiency of the chosen glazing complexes (glazing and solar shading) regarding their impact on the reduction of the cooling needs of the room (here, the reduction is seen as the difference of *"Annual cooling needs of the room"* (see *detailed results* after) between the configuration with double clear glazing (and no solar shading) and the configuration with the selected glazing complex). On the right side of the screen (see Figure 3), these values are displayed on a scale defined by the minimum and maximum values of coolings needs reduction obtained in the tool (for the selected use). This permits a precise comparison of the selected combinations. Also, in the center of the screen, symbols are used to describe in a simple way the impact of each selected combination: '/' for negligible protecion; '+' for low protection; '++'for medium protection; '+++' for high protection. These categories were calibrated by qualifying all internal shading devices for north orientation as negligible protection and all external shading devices for south as high protection.

Daylight harvesting

This criterion compares the daylight penetration through the glazing complex. It is based on the "*Daylight harvesting*" criterion presented in the *detailed results* section of the tool (see after). For the selected use and orientation, it expresses the daylight penetration through the glazing and solar shading combination (mean for summer and winter conditions) in relative terms in relation to the maximum value obtained for the double clear glazing configuration (without solar shading). The scores obtained depend on the position of the chosen solar shading on a scale defined by the minimum (0%) and the maximum (100%). As already seen for the "overheating protection" criteria, these values are displayed on a scale on the right side of the screen to ease precise comparison. Also, the following symbols are used to describe the behavior of each selected combination: '+' for poor daylight supply (0 to 10%); '++' for moderate daylight supply (10 and 23%); '+++' for good daylight supply (23 to 100%). Theses boundaries were calibrated to highlights the best cases with shading devices.

Glare protection

This criterion compares the impact of the chosen glazing complex on protecting against glare. It is based on the "*Glare protection*" criterion (see *detailed results*). The scores obtained depend on the category of solar shading for this criterion. The following symbols are used: '/' if no solar shading is present, '+' for low protection; '++' for medium protection; '+++' for high protection.

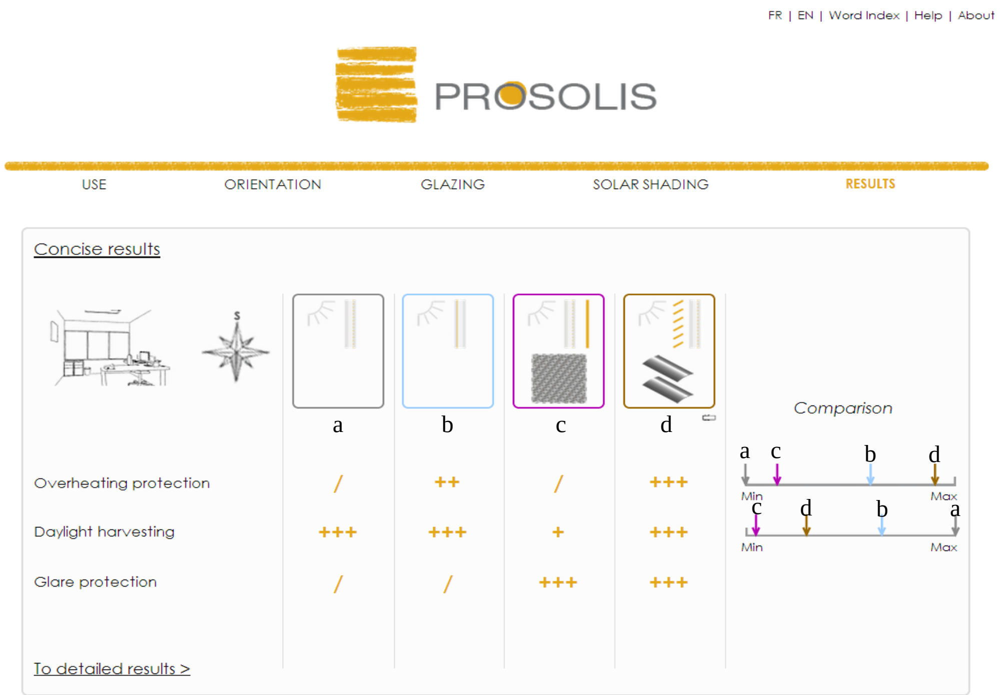


Figure 3 Concise results obtained for the comparison of the following combinations: (a) *double clear glazing*; (b) *reflecting double glazing*; (c) *double clear glazing with internal screen (serge grey)*; (d) *double clear glazing with external venetian blinds (dark grey slats with specular reflection).*

DETAILED RESULTS

This screen (Figure 4 and 5) is used to compare more in details the thermal and visual characteristics of multiple (up to four) different combinations of glazing and solar shading selected by the user. It includes 5 different sections: *Summary of choices; Glazing properties; Solar shading properties; Solar energy properties of the combination glazing and solar shading; Light properties of the combination glazing and solar shading.*

▾ Summary of choices

Use	Office space
Orientation	South

	CONFIGURATION 1	CONFIGURATION 2	CONFIGURATION 3	CONFIGURATION 4
Glazing				
Type	Clear double glazing	Reflecting double glazing	Clear double glazing	Clear double glazing
Solar shading				
Type	-	-	Screen	Blinds
Position	-	-	Interior	Exterior
Colour	-	-	Grey	Dark grey
Type of reflexion	-	-	-	Specular reflexion
Fabrics type	-	-	Sergé	-

▾ Glazing properties

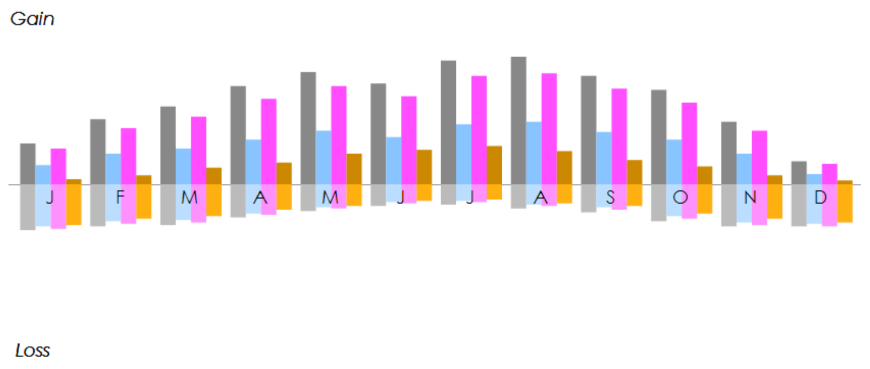
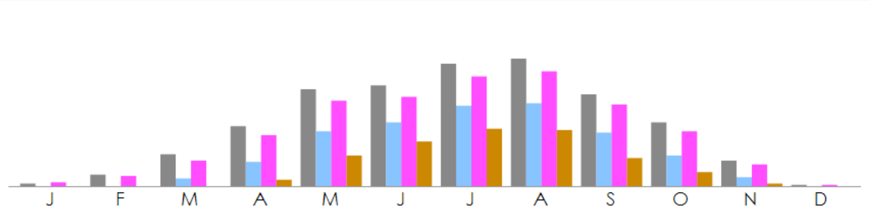
g [-]	0.62	0.30	0.62	0.62
U [W/m²K]	1.2	1.0	1.2	1.2
τ_v [%]	77	50	77	77

▾ Solar shading properties

Screen properties				
OF.	-	-	4.2	-
$\tau_{e,n-h}$ [%]	-	-	7.1	-
$\tau_{e,n-diff}$ [%]	-	-	2.9	-
$\tau_{e,n-n}$ [%]	-	-	4.2	-
ρ_e [%]	-	-	19.0	-
α_e [%]	-	-	73.9	-
$\tau_{v,n-h}$ [%]	-	-	5.4	-
$\tau_{v,n-n}$ [%]	-	-	4.2	-
Slats material				
ρ_e [%]	-	-	-	39.0
ρ_v [%]	-	-	-	44.5
Classes according to NBN EN 14500 and NBN EN 14501 ?				
Protection against total heat transfer	-	-	0	-
Protection against direct transmittance	-	-	4	-
Protection against secondary heat transfer	-	-	0	-
Opacity	-	-	0	-
Glare control	-	-	3	-
Night privacy	-	-	2	-
Visual contact to exterior	-	-	2	-
Daylight supply	-	-	1	-
View through				
Daytime conditions View from the inside				
Nightime conditions View from the outside				

Figure 4 Detailed results - Solar shading properties- obtained for the comparison of the following combinations: (a) *double clear glazing*; (b) *reflecting double glazing*; (c) *double clear glazing with internal screen (serge grey)*; (d) *double clear glazing with external venetian blinds (dark grey slats with specular reflection).*

Solar energy properties of the combination glazing and solar shading

Normal incidence values		0.29		
g_{tot} [-]	0.57	0.26	0.50	0.08
τ_e [-]	0.49	0.03	0.03	0.05
q_i [-]	0.08	1.00	0.47	0.03
Fc [-]	1.00	1.00	0.88	0.14
Contextualized data				
Thermal balance of the glazing-solar shading complex [kWh]				
Cooling needs of the room [kWh]				
Annual cooling needs of the room [kWh/year]	1726	959	1531	564
Impact of solar shading on cooling needs [kWh/year]	0	0	-195	-1162

Light properties of the combination glazing and solar shading

Normal incidence values				
τ_v [%]	78.40	70.80	4.40	8.10
Contextualized data				
Glare control	Weak	Weak	High	High
Daylight supply				
Winter [-]	0.99	0.64	0.05	0.30
Summer [-]	0.73	0.48	0.04	0.20

Figure 5 Detailed results – Solar energy and light properties of the combination "glazing and solar shading" - obtained for the comparison of the following combinations: (a) *double clear glazing;* (b) *reflecting double glazing*; (c) *double clear glazing with internal screen (serge grey)*; (d) *double clear glazing with external venetian blinds (dark grey slats with specular reflection)*.

Summary of choices

This section (see Figure 4) summarises the selections made by the user: *use, orientation, glazing, solar shading, type, position, colour, type of reflectance, fabric type*.

Glazing properties

This section (see Figure 4) presents the property values of the glazing selected by the user: *Solar factor; Thermal transmittance factor (U-value); Light transmittance*.

Solar factors and light transmittance factors of the glazing were determined by the glazing manufacturer in compliance with the standard NBN EN 410:1998.

Thermal transmittance factors of the glazing were determined by the glazing manufacturer in compliance with the standard NBN EN 673:2011.

Solar shading properties

First, this section (see Figure 4) covers the detailed values of the properties of the solar shading selected by the user. For **screens** the following properties are described**:** *Openness factor*; *Solar transmittance (normal-hemispherical, normal diffuse, normal-normal)*; *Reflectance* and *Absorption*; *Light transmittance (normal-hemispherical, normal diffuse, normal-normal)*. For **blinds**, *Solar and Light reflectances* are described.

The **solar and light transmittance, reflectance and absorption** values were determined in compliance with the standard NBN EN 14500:2008. The **screen openness factor** was based on a physical measurement of the proportion of holes in compliance with Annex B of this standard.

The **classifications** for *protection against total heat transfer*, *protection against direct transmittance*, protection *against secondary heat transfer, opacity, glare control, night privacy, visual contact with the outside* and *daylight supply* are then described according to the standard NBN EN 14501:2005. This standard establishes classifications for these properties ranging from 0 to 3 or 4: 0 being a property resulting in very little effect and 4 being a property resulting in a very good effect.

Closing this section of the detailed results, **outwards view in daytime conditions and inwards views in nighttime conditions** are given. These images were determined for standard daytime and nighttime observation conditions. They were taken in a laboratory under controlled lighting conditions, in particular with regard to background contrast differences, thus generating an accurate reproduction of internal and external views. The observation distance was set to 80 cm from the solar shading device. Under daytime conditions, a lighting contrast with a ratio of 1 to 300 was generated between the vertical plane on which the solar shading device is positioned and the background. Under nighttime conditions, this lighting contrast was maintained at a ratio of 1 to 4000.

Energy properties of the combination glazing and solar shading

First, this section (see Figure 5) covers **properties of the glazing and solar shading combination at normal incidence**: *Solar factor (g_{tot}); Direct (τ_e) and secondary heat transfer factor (q_i); Shading factor (F_c)*. These values were obtained using the Window 7.2 software (LBNL, 2013). The calculation was made taking into account on the one hand glazing data issued by manufacturers, in compliance with the standard NBN EN 410:2011 and on the other hand the spatial behavioural properties of the solar shading (using Bidirectional Scattering Distribution Functions (BSDF) (Deroisy et al, 2013)).

Then, this section presents the energy **properties characterising the glazing and solar shading combination in the context** (use and orientation) defined by the user: *heat balance of the complex; cooling needs of the room; impact of solar shading on cooling needs*. All of these results were calculated by dynamic thermal modelling using EnergyPlus V8.1 software (DOE, 2013). These simulations were performed by series of 5-minutes time intervals over a standard year in Brussels (ASHRAE, 2001). The simulations took place for the geographic location of Uccle. The results for this criterion must therefore be considered for this geographic position (Latitude 50.8°N). All of the optical properties of the glazing and solar shading combinations used in the thermal simulation were introduced based on prior detailed modelling results (integrating BSDF measurements of solar screen properties) derived from the WINDOW 7.2 software via a BSDF formalism (Dartevelle et al., 2013). An automated solar shading management system was modelled. This was based on a criterion of 150 W/m² of total solar radiation on the window to trigger the closing of the solar shading device. For more representative results, a solar shading device was modelled on all windows with the orientation selected by the user. No shading caused by the outdoor environment was taken into account. The **heat balance** is obtained by the sum of the monthly gains and losses of the room by conduction, radiation and convection through the glazing and solar shading combination (DOE, 2013(2)). The **monthly cooling needs** of the room analyzed are calculated based on an indoor temperature of 25°C that must not be exceeded during occupancy. The **impact of solar shading on cooling needs** is quantified based on the difference in cooling needs between the considered case and the same case without solar shading (all other considered assumptions (use, orientation, glazing) being identical).

Light properties of the combination glazing and solar shading

This section (see Figure 5) covers on the one hand the light properties of the combination glazing and solar shading at normal incidence: *Light transmittance*. The **light transmittance** values of the different glazing and solar shading combinations were obtained using the Window 7.2 software tool.

On the other hand, this section covers the properties **characterising the glazing and solar shading combination in the context** (use and orientation) defined by the user: *Glare control*, *Daylight supply* (summer and winter) according to the selected orientation. Information regarding **glare control** was collected by collating the results from advanced computer simulations performed using LightTools 8.1 software (OSG, 2013), integrating precise data on the properties of the materials used to constitute the solar shading devices (BSDF data) and brightness measurements for solar shading devices under real external exposure conditions calculated by Photolux 3.2 (SE, 2012) software based on High Dynamic Range (HDR) images. The direction of observation of the solar shading is perpendicular and the distance of the observer from the solar shading is such that with an average solar altitude, direct view of the sun is impossible. Three categories have been created, distinguishing the mean amount of light perceived through glazing and solar shading combinations: *Low glare control (mean brightness greater than 3000 cd/m²⁾; Medium glare control (between 1000 and 3000 cd/m²⁾; High glare control (less than 1000 cd/m²).* The information regarding "**daylight harvesting**" was also generated by computer simulations using LightTools 8.1 software and integrating BSDF data measured for the materials used to constitute solar shading devices. It represents the total light flow through the combination with the solar shading device extended where applicable and for a perfectly clear sky. It was calculated for each orientation on a vertical reference plane located behind the glazing complex and exposed to a cumulated clear summer (15 June) and winter (15 December) sky. This criterion is expressed in relative terms compared to the maximum value obtained for all considered configurations.

CONCLUSION

The PROSOLIS web tool proposes an original multi-criteria approach for comparing precisely performance levels of common types of glazing complexes (glazing and shading devices). It permits to easily obtain and compare their detailed and contextualized energy and light characteristics. In this way, this tool should help designers to choose glazing complexes corresponding to their needs.

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Improving the Energy Efficiency of the Building Stock: A Bottom-up Model and its Application in an Online Interactive Portal

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ABSTRACT

There is an urgent need to reduce energy uses in new and retrofitted buildings. In Europe, energy consumption in the building sector still represents more than 40% of the final energy use. Emerging countries are also concerned by such issues at even wider levels because of the huge demographic growth they are witnessing. Numerous research studies have highlighted the need to produce more efficient buildings, but also to retrofit the existing building stock. However, research methods and tools that allow a precise quantification of energy uses in buildings and energy savings related to various actions (insulating the roofs, changing the glazing, behavioral changes, etc.) are mainly dedicated to trained professional users, thus neglecting the huge potential energy savings that is linked to individual actions undertaken by citizens in their dwellings. In this context, the main aim of our research is to raise awareness of energy efficiency in residential buildings and encourage positive changes to the energy efficiency of the building stock, starting at the individual scale. This paper first presents the methodology that allows a precise energy assessment (heating, cooling, ventilation, lighting, appliances and cooking) of buildings (at the house, neighborhood, city and region scales) on the basis of a "bottom-up" approach. This methodology uses a typological classification of buildings, thermal simulations and local surveys. In this paper, this methodology is applied to the Walloon (Belgium) building stock. Many parameters are defined and taken into account to capture the specificities of numerous types of buildings (e.g., the number of floors, common ownership, orientation, thermal performances, ventilation, etc.). Several occupation modes are modelled to capture the impact of occupants' behavior on energy consumption. To take into account the impact of urban form, correction factors are defined and applied according to the type of neighborhoods in which the buildings are located. All things considered, 250,000 individual results are obtained and stored in a huge database. Linear extrapolations and correction factors are used to extrapolate and apply these results to any type of residential building in Wallonia. This methodology is then used to develop an online portal that aims to strengthen citizens' awareness of the necessity for ecological changes in the building sector and encourage individual actions to improve the energy efficiency of buildings. This tool allows for a transfer of the main results of a two-year scientific research effort to citizens in a very simple and intuitive way. Although the results presented in this paper are focused on Wallonia (Belgium), the research is easily reproducible to other territories by adapting local parameters.

INTRODUCTION

There is an urgent need to reduce energy uses in new and retrofitted buildings. In Europe, energy consumption in the building sector still represents more than 40% of the final energy use. Emerging countries are also concerned by such an issue at even wider levels because of the huge demographic growth that they are witnessing. Numerous research efforts have highlighted the need to produce more efficient buildings, but also to retrofit the existing building stock, especially in Europe where the renewal rate of buildings is quite low. Moreover, several research and empirical results have demonstrated the significant impact of the behavior of housing occupants on energy consumption (e.g., de Meester et al., 2012; Santin et al., 2009). However, research methods and tools that allow a precise quantification of energy uses in buildings and energy savings related to various actions (insulating the roof, changing the glazing, behavioral changes, etc.) are mainly dedicated to trained professional users, thus neglecting the huge potential energy savings linked to individual actions undertaken by citizens in their dwellings. Citizens are, in fact, the first actors who can concretely act to alter the energy consumption in residential buildings. However, although an increasing number of households are paying attention to their energy consumption and are motivated to undertake light or heavy renovation work, they do not know what action to choose and are unaware of the impacts of renovation in terms of comfort, energy savings, etc. In fact, efforts to promote energy efficiency remain concentrated on the general guidelines; in particular, user-friendly assessment tools dedicated to a non-specialized audience (local authorities, developers, citizens) are lacking (Tweed and Jones, 2000). Most existing BPS (Building Performance Simulation) tools (e.g., TRNSYS, Comfie+Pleiades, Energyplus, phpp) are designed by engineers for use by other trained engineers, which make them too complicated to quickly evaluate the performance of different design concepts or strategies (Attia et al., 2012). Amongst the existing simplified evaluation tools, Gratia and De Herde (2002a and 2002b) developed a simple design tool for the thermal study of dwellings and office buildings. The calculation of the energy consumption is mainly dedicated to architects and based on the results of dynamic thermal software. Performing an assessment by using a simple design tool is much easier than performing an assessment while using this thermal simulation software, but the values of many parameters that are not often known by households and local authorities are still required.

In this paper, we argue that the implementation of energy efficiency measures into concrete policies and the popularization of academic research to the general public (citizens, local authorities, policy makers, etc.) are crucial to ensure a more sustainable development of our territories and to reduce energy consumption in buildings. The main aim of our research is, thus, to encourage positive changes to the energy efficiency of the building stock, starting at the individual scale, by transferring the main results of a two-year research to a non-specialized audience. The need for this type of research lies in the fact that its dissemination is for "normal people," for them to have the necessary information to conduct themselves and their homes more energy efficiently.

To this end, this paper first presents the methodology that enables a precise assessment of energy uses in buildings. This methodology is applied to the Walloon building stock and a huge database comprised of more than 250,000 individual results is produced. Then, the methodology and the database are used to develop an online portal that aims to raise public awareness on energy efficiency in buildings.

METHODOLOGY: A BOTTOM-UP MODEL

A methodology was developed to assess energy uses (energy requirements for space heating, cooling, ventilation, electrical appliances, cooking and domestic hot water) in residential buildings at an individual scale. This methodology must allow researchers to precisely assess energy uses at the individual building scale, but also to draw trends, at the neighborhood, city and regional scales. This methodology combines several research methods and tools, including a typological classification of buildings, dynamic thermal simulations, surveys, etc. The energy consumption levels related to heating, cooling and ventilation are derived from dynamic thermal simulations. The energy consumption levels related to domestic hot water, electrical appliances and cooking are based on regional empirical surveys and are linked to the number of inhabitants in each dwelling. In this paper, this methodology is applied to the Walloon (Belgium) building stock. However, this work is also reproducible to any other territory by adapting local parameters.

Parameters taken into account to develop the bottom-up model

The parameters that were taken into account to build the bottom-up model are related to (A) the environment in which the building is located, (B) the characteristics of the building, (C) the thermal performances of the envelope and the systems. They are explained below and summarized **in Figure 1**.

As far as the environment in which the building is located is concerned, 1,347 possibilities were defined to cover the variation of the climate (see column A.1 **in Figure 1**) (in comparison with Brussels, a temperate climate in the northern part of Europe) in Wallonia. A coefficient based on degree-day was attributed to each location and then applied to thermal simulation results (performed with Brussels' climate). Eight main types of residential neighborhoods (A.2) were defined (dense urban core, continuous urban, semi-continuous urban, homogeneous semi-continuous and social housing, villages and rural cores, suburban neighborhoods, isolated rural, great sets) on the basis of a typological classification of the whole Walloon building stock (Marique and Reiter, 2013). Simulations were performed on 24 selected representative neighborhoods with Townscope software (Teller and Azar, 2001): 500 points were randomly defined on the facades and roofs of each neighborhood and an assessment of solar gains was performed in order to define corrections factors according to the density of the neighborhood. These correction factors were stored in the database and then applied to the results of thermal simulations of buildings, in order to take into account the diminution of solar gains on facades and roofs, according to the built density of the neighborhood in which the considered building is located.

A. ENVIRONMENT		B. TYPOLOGY				C. THERMAL PERFORMANCES AND SYSTEMS								
1. Climate	2. Neighborhood	1. Housing type	2. Number of floors	3. Common ownership	4. Orientation	1. Wall type	2. Slab insulation [cm]	3. Wall insulation [cm]	4. Roof insulation [cm]	5. Glazing	6. Ventilation	7. Thermostat	8. Heating system	9. Fuel type
Choice amongst 1347 locations and their related degree days	Dense downtown	Wide house	1,5	Detached or semi-detached	North	Solid	0	0	0	Simple, double-old or double-new	A	18°C	Hot water boiler condensing	Natural gas
				Terraced	North or East				16					
	Continuous urban		2	Detached or semi-detached	North		3	3	3				Hot water boiler non condensing	Gazole
				Terraced	North or East				16					
	Semi-continuous urban	Narrow house	1,5	Detached or semi-detached	North		6	6	6				Electric resistance heating	Propane
				Terraced	North or East				16			20°C		
	Homogeneous semi-continuous or social city		2	Detached or semi-detached	North		10	10	10	Double-old, double-new or triple	C or D		Heat pump	Butane
				Terraced	North or East				20	Double-new or triple				
	Village or rural nucleus		3	Semi-detached	North	Cavity	15	15	15	Double-old, double-new or triple			Micro-CHP	LPG
				Terraced	North or East				30	Double-new or triple				
	Suburban subdivision		4	Terraced	North or East		20	20	20	Double-old, double-new or triple			stove	Coal
		Wide crossing apartment	1	Top, intermediate or ground	North or East				30	Double-new or triple		20-16°C		
	Isolated rural	Narrow crossing apartment	1	Top, intermediate or ground	North or East		25	25	25	Double-old, double-new or triple			Radiator or electric heater	Wood (4 forms)
		Three fronts apartment	1	Top, intermediate or ground	North				35	Double-new or triple				
	"Great Sets"	One front apartment	1	Top, intermediate or ground	North, East, South or West		30	30	30	Double-old, double-new or triple			Electric storage heater	Electricity
		Corner apartment	1	Top, intermediate or ground	North, East, South or West				35	Double-new or triple				

Figure 1 Summary of the parameters related to (1) the environment in which the building is located, (2) the characteristics of the building, (3) the thermal performances of the envelope and the systems.

As far as the characteristics of the buildings are concerned, 60 main types of dwellings were defined to cover the whole Walloon residential building stock on the basis of the main characteristics of Walloon dwellings, as identified in previous research (Evrard et al., 2012; Kints, 2008). The typology is comprised of houses and apartments. For houses, the characteristics that were taken into account to build the typology are the plan orientation (B.1) (perpendicular or parallel to the street), the number of floors (B.2) (one and half, two, three or four), the common ownership (B.3) (detached, semi-detached or terraced house) and the orientation (B.4) of the building (north, east, south, west). For apartments, the characteristics were the plan configuration (B.1) (wide crossing, narrow crossing, three fronts, one front or corner apartment), the position (B.3) of the apartment in the building (ground floor, intermediate floor or top floor apartment) and the orientation (B.4) of the building (north, east, south, west). Each of the 60 types has a fixed heated surface area. Extrapolations are then performed to extend the results obtained in the thermal simulations to similar types of buildings presenting different heated surface areas (see below).

As far as the thermal performances of the housing are concerned, two types of wall (C.1) are defined (solid or cavity). The insulation in the slabs and the walls (C.2 and C.3) vary from 0 to 30 centimeters. The insulation in the roofs (C.4) varies from 0 to 35 centimeters. The glazing type (C.5) may be simple, double-old, double-new or triple. The glazing surface area on each façade is defined according to the housing type. For all types of dwellings, the ceiling height is worth 2.4m; no attachments are modeled as such, but they can be taken into account by including them in the total area of the dwelling; the basement floor is not taken into account.

Three ventilation modes (C.6) are defined: natural ventilation (type A), ventilation with mechanical extraction (type C) and double flow ventilation with heat recovery (type D). For the ventilation of type A, the windows are opened for an internal temperature higher than 25°C and are closed when this temperature drops down to 23°C. In the case of ventilation of types C and D, air flows are defined according to the Belgian requirements (NBN, 2008). The heat recovery system efficiency is set at 85%.

Three types of thermostat (C.7) are defined (18°C constant during day and night, 20°C constant during day and night and 20°C with a reduction to 16°C in a daily work-pattern and during night. No weekly or annual profile has been defined.). Eight types of heating systems (C.8) and 11 types of fuel (C.9) were taken into account. For each type, a correction coefficient was used to integrate the efficiency of the heating system (production, distribution and emission). These coefficients come from the Belgian regulation (PEB, 2008 and 2012).

A couple of rules of combinations were finally defined to eliminate nonrealistic cases (for example, a building with 20 cm of insulation and simple glazing). In all, 250,000 types of buildings were defined.

Assessment of energy uses in buildings

The TRNSys thermal simulation software was then used to perform an energy consumption analysis of space heating needs and electricity needs for ventilation systems and solar gains for each of the 250,000 cases in the Belgian context (the climate of Brussels without any surroundings buildings). Cooling was not considered in the analysis because cooling needs are minimal in Belgium. In these simulations, internal gains were defined according to Massart and De Herde (2010), such as 70W/person for occupation and 6W/m² and 4W/m² for nominal power lighting and appliances, respectively. They are functions of the dwelling's surface and of the number of occupants which are set in function of the type of housing. Internal gains are also set according to a daily and weekly schedule. In addition, three standards defined by the European Energy Performance of Buildings Directive (EPBD) were added: the low-energy standard, the very low-energy standard and the passive standard, which correspond to annual heating requirements lower than 60 kWh/m².year, 30 kWh/m².year and 15 kWh/m².year, respectively.

The energy consumption related to appliances and cooking are respectively evaluated at 1,000 kWh per person and per year and 165 kWh per person and per year in Belgium on the basis of a local survey of energy uses by households (ICEDD, 2008). The energy consumption related to domestic hot water is assumed to be dependent on the number of inhabitants. We consider that each inhabitant needs 100 liters of cold water (10°C) and 40 liters of hot water (60°C) per day in accordance with the regional trends (ICEDD, 2008). The number of inhabitants is dependent on the surface area of the dwelling.

Storage of the results

The results of the energy assessments (space heating, cooling, ventilation, appliances, cooking and hot water) were stored in a huge database comprised of seven parts: Part 1 is dedicated to the based degree-days coefficient, Part 2 stores the solar factors depending on the built density of the neighborhood in which the building is located, Part 3 is dedicated to space heating requirements and electricity needs for the ventilation system, Part 4 relates to the characteristics of the heating systems, Part 5 addresses domestic hot water requirements, Part 6 relates to cooking requirements and Part 7 is dedicated to electrical appliances requirements.

Part 3 (space heating energy needs and electricity needs for the ventilation system) is comprised of seven columns, **as illustrated in Table 1**. The first column includes a unique numeric code that allows one to directly and easily identify the corresponding building and its characteristics: each item of the code corresponds to a specific variation of a parameter and provides the identity card of the tested case.

Table 1. Example of the database for the space heating and ventilation needs

Code	m_q	p_q	m_s	p_s	m_v	p_v
1_3_2_1_c_1_g_3_2_1	41.9	38.6	8.1	486	2.2	-23.1
1_3_2_1_c_1_g_3_2_2	54.1	142.3	13.9	768.9	2.2	-23.1
1_3_2_1_c_1_g_3_2_3	49.1	105.5	8.1	486	2.2	-23.1
1_3_2_1_c_1_g_3_3_1	24.7	558.9	8.1	486	6.9	-73
1_3_2_1_c_1_g_3_3_2	32.4	792.5	11.3	646.2	6.9	-73
1_3_2_1_c_1_g_3_3_3	30.2	681.6	8.1	486	6.9	-73

Columns 2 and 3 are used to store the slope (m_q) and the intercept (p_q) of the linear extrapolation used to generalize space heating energy needs obtained through thermal simulations to any similar building that presents a different heated surface area. Columns 4 and 5 (m_s and p_s) store parameters related to solar gains. The two last columns (m_v and p_v) are used to calculate the electrical needs of the ventilation's fans. The coefficients that are used to transform energy needs into fuel consumptions, primary energy consumptions, CO_2 emissions and into an estimation of the annual cost are also stored in the database. These coefficients are used with an identification number that depends on the systems used in the simulations.

Extrapolation and final results

Energy needs for space heating, cooling and ventilation are obtained by using the surface area of the dwelling (S) and the data from the linear extrapolation (m_q and p_q) stored in the database. Afterward, a first correction is applied to energy need for space heating, cooling and ventilation to take into account the neighborhood in which the dwelling is located and the loss of solar gains related to the density of the neighborhood (F_s, m_s and p_s). A second correction factor (C) is applied to take into account the location of the dwelling on the territory and the corresponding degree-days in comparison with Brussels' climate. Finally, the annual space heating consumption (Q_{SH}) – expressed in kWh/year – is obtained by multiplying the space heating need by the efficiency of the whole heating installation (SH_n), **as shown in equation 1**.

$$Q_{SH} = [(m_q * S + p_q) + (m_s * S + p_s) \text{ x } (1\text{-}F_s)] * C * SH_n \tag{1}$$

Electricity consumption of the ventilation system (Q_{VT}) – in kWh/year – is calculated on the basis of the surface area (S) and the data of a linear extrapolation (m_v and p_v) from the heating database, **as shown in equation 2**.

$$Q_{VT} = (m_v * S + p_v) \tag{2}$$

Energy needs for domestic hot water, electric appliances and cooking depend on the number of inhabitants in the dwelling (N). Such statistics also incorporate data from regional surveys, **as shown in**

equations 3, 4 and 5. The energy need for hot water (Q_{HW}) takes into account the quantity (liter) of hot water consumed annually ($L_{liter/year}$), the difference between the hot and cold water temperatures (ΔT) and the water heat capacity (C_v), **as shown in equation 3**. As for space heating consumption, energy consumptions for domestic hot water, appliances and cooking – expressed in kWh/year – are obtained by multiplying the respective energy need by the corresponding yield coefficient (HW_n, EA_n and CK_n respectively).

$$Q_{HW} = (L_{liter/year} * N * \Delta T * C_v) * HW_n \tag{3}$$

$$Q_{EA} = (-40 * N^2 + 550 * N + 1765) * EA_n \tag{4}$$

$$Q_{CK} = (200 * N) * CK_n \tag{5}$$

Finally, the household annual consumptions can also be converted into primary energy consumptions, CO_2 emissions and euros by applying the conversion coefficients stored in the database.

Validation and relevance of the results

The methods and data used to build the database were presented extensively in previous papers (Marique and Reiter, 2012; Marique et al., 2014). The software used in the analysis has namely been validated by the International Energy Agency Bestest. We used the database to calculate the energy consumption of the whole building stock of Wallonia and compared this result with an in-situ survey ("annual thermal survey") carried out by ICEDD (2008) on the basis of the real consumption of Walloon households. Differences between our simulations and figures from ICEDD are worth a maximum of 8.2%, which was considered to be acceptable.

AN ONLINE INTERACTIVE PORTAL DEDICATED TO CITIZENS

The model developed to assess energy uses in Walloon buildings and the numerous results stored in the database were then used to develop several types of applications that benefit different types of users (citizens, architects and urban planners, local or regional authorities, etc.). Due to the restricted length of this paper, in this section we will only present the online interactive portal that we developed for citizens.

The main aim of this portal is to raise awareness of current energy issues and offer concrete solutions to reduce energy uses in buildings by arguing that citizens are the first actors who can concretely act to improve energy efficiency in residential buildings (the building stock is mostly private in Belgium). However, citizens often face huge difficulties in highlighting key parameters and strategies in the energy efficiency of their dwellings and in identifying the most efficient retrofitting work to perform in each particular case. To this end, the online portal that we developed makes available, in a very simple and intuitive way, more than 250,000 results of dynamic thermal simulations to a non-specialized audience. This knowledge aims to help them to assess energy uses in their dwellings and to make the best choices to improve its energy efficiency. Thus, it addresses one major shortcoming of existing simulation tools (BPS tools): the accessibility to citizens and local stakeholders.

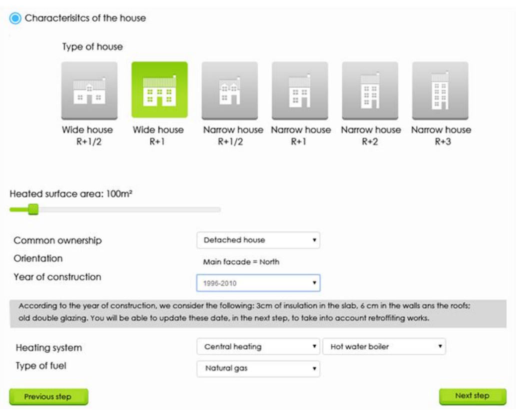
The online portal comprises three different evaluation tools, two of which are specifically dedicated to citizens. The simplified evaluation allows an individual user or household to assess building energy consumption on the basis of limited information. Completion of the questionnaires is very simple to allow the user to complete them quickly and without specific data and technical knowledge. The detailed evaluation allows an individual user or household to assess building energy consumption more precisely than the simplified evaluation. The questionnaires are more complex, but the results are closer to the real situation of the user and can be strongly personalized.

To ensure a wide diffusion of the portal, the questionnaires used in the evaluation tools are simple, intuitive and easy to complete, **as illustrated in Figure 2.** The results are also expressed in a very simple form, **as seen in Figure 3,** for energy uses in the considered dwellings. Several strategies to improve the energy efficiency of the tested building are then provided (such as the insulation of the roof, the change of the glazing, the insulation of the whole building's envelope, behavioral changes) to the user. They are personalized according to the characteristics of its dwelling. The quantification (in kWh/year and in %) of the potential energy savings linked to each strategy is also provided on the basis of the results stored in the database and the unique code used to store the results (**Table 1**). In addition to the results presented in this paper that are focused on energy uses in buildings, additional indicators are also provided in the online portal. In particular, it is possible to take into account the impact of the location of the dwelling on the daily mobility of inhabitants by assessing the energy consumption for daily mobility. The use of renewable energy is also included in the portal on the basis of the methodology developed by Marique et al. (2013) and Marique and Reiter (2014). The final version of this portal is online as of the end of August 2014 at www.solen-energie.be (only in French for the moment).

In addition to the development of this online portal, numerous actions have been – and will be-undertaken by the research teams to promote this initiative and to extensively raise awareness of the importance of improving energy efficiency in buildings, starting from the individual scale. These actions are dedicated to a wide range of actors: students in architecture and urban planning, researchers, local and regional stakeholders, private developers, architects, and, of course, citizens.

It is too early to provide the results of usability testing since the final version of the tool has only been online for a few weeks, but the first simplified version of the portal that is solely comprised of suburban types of dwellings (Marique et al., 2012 and 2014) was launched between 2012 and August 2014. We have registered approximately 400 visits per month on the website. Direct interviews and workshops have shown positive feedback from users of the online interactive portal.

Last, but not least, in May 2014 the online portal and the research project that allowed its development were awarded the "Energy Globe Award" for Belgium, one of the world's most prestigious environmental awards (see also http://www.energyglobe.info/belgium2014?cl=english).



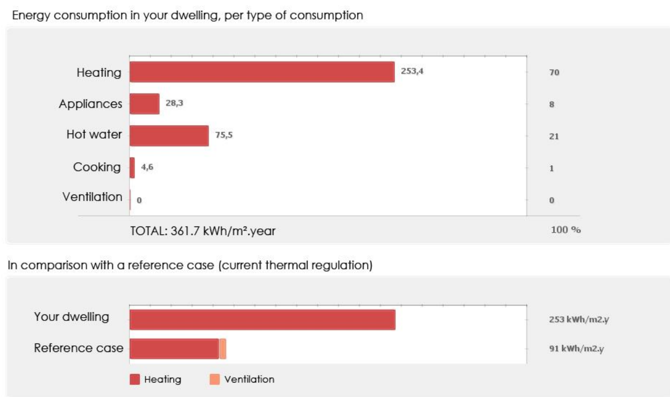


Figure 2 Example of the questionnaires provided in the online portal (left)

Figure 3 Example of results provided in the online portal (right)

CONCLUSIONS

This paper presented a methodology that enables one to precisely assess energy needs and energy consumption for space heating, cooling, ventilation, lighting, appliances and cooking within individual dwellings on the basis of a "bottom-up" approach. This methodology was based on a typological classification of buildings, thermal simulations, local surveys and linear extrapolations to cover a wide range of buildings and parameters. Among others, the impact of the location in which a dwelling is located is taken into account via the application of correction factors based on the built density of the neighborhood. This methodology was applied to the Walloon (Belgium) residential building stock to build a huge database that included more than 250,000 individual results.

This database was then mobilized to build an online interactive portal that aims to raise public awareness of energy efficiency in buildings. Thus, citizens are able to easily assess the sources of energy consumption for buildings. They may also compare these different energy consumption sources in order to determine relevant and personalized recommendations with which to reduce their energy consumptions. This interactive online portal represents the main results of an important two-year scientific research project dedicated to energy efficiency in Wallonia that is accessible to a large non-specialized audience, which is crucial in the scope of sustainable development.

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GIS-Based Urban Permeability Evaluation in the Urban Planning to Improve the Wind Environment – A Case Study in Wu Han, China

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ABSTRACT

Due to the rapid urbanization, the urban environment has been changed and deteriorated. One of reasons is lack of considering and implementing the climatic and environmental information into local urban planning. Thus, there is a need to develop a systematic method for city planners and policy-makers to make scientific and evidence-based decision in the urban climatic and environmental field. Taking Wu Han as an example, this study aims to provide a practical framework to identify planning goals and guidelines for master and district planning, based on the results of roughness modelling. Both meteorological information and 3D urban morphology data were simplified and integrated in Geographical Information System (GIS) to provide detailed spatial information of the urban permeability distribution. Based on this spatial distribution information, both the master and district planning goals for better urban wind environment can be particularly identified and corresponding planning strategies can be established. With this spatial urban permeability information and the joint effort from local town plans and policy-makers of the Planning Bureau of Government, urban planning strategies for different spatial scales and districts can well cooperate with each other and be interweaved into the whole urban planning process.

INTRODUCTION

In the last 20 years, major cities in China have undergone rapid urbanisation. Wu Han, with an area of some 8,500km^2 and a population of over 10 million, is located inland and west of Shanghai. It is one of the mega cities in China and is the country's high speed rail hub. In the summer months, Wu Han is hot; the average daytime temperature of the city is around 33 degrees Celsius. The city planners of Wu Han have been postulating the idea of urban air paths for a number of years for the making of their master plan. This study to better identify and quantify the wind path idea was commissioned by the City Planning Bureau of the Wu Han City Government in 2012. The study intended to provide evidence-based basis for Wu Han's planners.

OBJECTIVES

The study of outdoor natural ventilation often requires large-scale aerodynamics modelling. Both physical modelling (wind tunnel) and computational simulation modeling can provide data regarding the airflow within the urban canopy. However, conducting these modeling tests for a particular urban planning exercise is expensive and time consuming. Modeling results cannot keep up with the quick planning processes, as such, Ng (2011) opines that a methodology that uses a rougher understanding of the urban morphological implication to the urban wind environment can be more useful to planners. Given the growing concerns related to urban permeability evaluation and air paths detection in order to fit the requirements of practical urban planning, this study aims to:

1. Introduce the morphological method to model urban surface roughness and evaluate urban permeability;
2. Analyze urban permeability to detect potential air paths to improve urban performance in outdoor natural ventilation;
3. Highlight the implementation of modeling results in urban planning practices and interweave the modelling results into different urban planning stages, such as the master and district planning.

This study focuses on Wu Han as an example. By applying the morphological modelling method with Wu Han's local GIS data (3D building database), the planners can easily evaluate the urban permeability to understand the urban ventilation of the city for evidence-based decision making in urban planning.

STUDY APPROACH

Morphological method

The morphological method of surface roughness modelling (Grimmond and Oke, 1999, Lettau, 1969, MacDonald et al., 1998) is widely used to estimate the wind profiles in the urban boundary layer (UBL), as shown in Figure 1. Based on a 3D building database and current modelling method, Gál and Unger (2009) visualized and mapped the spatially averaged roughness length (z_0) in pixel at urban areas to diagnose the urban wind environment. To make the evaluation of urban permeability more practical and available to urban planners, some urban geometric parameters, such as frontal area density (λ_f) and site coverage ratio (λ_p) which were used to estimate roughness length (z_0) and zero-plane displacement height (z_d) (Grimmond and Oke, 1999), were directly used to evaluate the urban permeability (Ng et al., 2011, Wong et al., 2010).

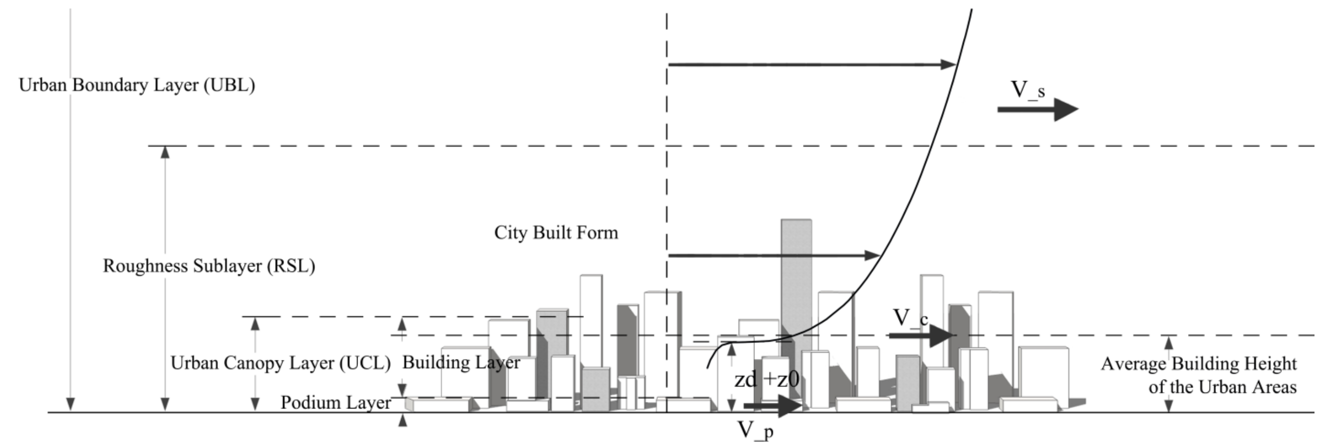

Figure 1 *Wind speed profile, podium layer, building layer, urban canopy layer, and roughness sublayer. V$_{_p}$: pedestrian-level wind speed, V$_{_s}$: the wind speed at the top of roughness sublayer (RSL) (*Ng et al., 2011*).*

The basic assumption in the current morphological methods, such as the models provided by Macdonald (1998), Lettau (1969), and Bottema (1996), was stated by MacDonald et al.(1998) as:'...we assume that there is negligible wake interference between the surface obstacles and that the mean velocity profile approaching each obstacle is logarithmic. '. Due to this assumption, the reason why these models are only valid when frontal area density (λ_f) is less than about 0.3-0.5 could be obvious; that is, with the roughness increasing, the mean velocity profile approaching each obstacle is not logarithmic because the interference among obstacles dominates the recirculating flow which dominate the flow near the ground.

It is why the displacement height (d) needs to be introduced into the logarithmic velocity profile (MacDonald et al., 1998). Above the displacement height, the mean wind profile approaching the obstacle becomes logarithmic again. Therefore, it is instructive to be noticed that the λ_f* (frontal area density above the displacement height) could be better to estimate z_0 than λ_f; and in this case, the mean wind speed below the displacement height (a new smooth surface) is assumed to be zero (MacDonald et al., 1998). The above analysis brings a great trouble to the practical application of the near ground wind speed estimation at high density urban areas. A lot of reliable wind tunnel experiments have proof that the wind speed below the displacement is not zero at high density urban areas.

Therefore, the wind speed below the displacement height could depends on the building geometries such as $\lambda_f{}'$ (frontal area density below the displacement height), instead of $\lambda_f{}^*$ by which the mean wind profile above the displacement height can be well identified. The cross-comparison conducted by Ng, et al. (2011) supported the above analysis; that is, the VR (the ratio of pedestrian-level wind speed to the wind speed at the reference height) is well related with $\lambda_f{}'$ ($\lambda_{f\,(0\text{-}15m)}$), rather than $\lambda_f{}^*$ ($\lambda_{f\,(15\text{-}60m)}$) and $\lambda_{f\,(0\text{-}60m)}$. In particular, the frontal area density ($\lambda_{f(z,\theta)}$) at a height increment of 'z' is calculated as (Burian et al., 2002):

$$\lambda_{f(z,\theta)} = \frac{A(\theta)_{proj(z)}}{A_T} \quad (1)$$

Where $A(\theta)_{proj(z)}$ is the frontal area facing the incoming wind direction θ in the height band 'z' and A_T is the site area. In contrast to the frontal area index ($\lambda_{f(\theta)}$), which is an average parameter for the entire urban canyon layer, $\lambda_{f(z,\theta)}$ focuses on the urban morphology at the height band 'z'.

To evaluate urban permeability based on the annual outdoor natural ventilation performance, $\lambda_{f(z,\theta)}$ calculated at different prevailing wind directions were averaged based on the respective annual wind probabilities ($P_{\theta i}$):

$$\lambda_{f(z)} = \sum_1^i \lambda_{f(z,\theta)} \cdot P_{\theta,i} \quad (2)$$

Where $\lambda_{f(z)}$ is the annually averaged $\lambda_{f(z,\theta)}$, and $P_{\theta,i}$ is the annual wind probability in the i_{th} wind direction θ. By using a high-resolution (1 m × 1m) building height database, a self-developed program embedded as a VBA script in the ArcGIS system is applied to calculate the frontal area density $\lambda_{f(z)}$ in Equation 2.

Classification

Based on the linear relationship reported by Ng et al.(2011), as shown in Figure 2, the values of $\lambda_{f(z)}$ were classified as follows: (1) $\lambda_{f(z)} \leq 0.35$; (2) $0.35 < \lambda_{f(z)} \leq 0.45$; (3) $0.45 < \lambda_{f(z)} \leq 0.6$; and (4) $\lambda_{f(z)} > 0.6$. This classification aims to statistically weigh the effects of different values of $\lambda_{f(z)}$ on the pedestrian-level natural ventilation performance, and to detect the potential air paths (the areas with low surface roughness) in high-density urban areas. For instance, Class 4 ($\lambda_{f(z)} > 0.6$) indicates that the wind velocity ratio ($VR_{w,j}$) maybe less than 0.1, which implies very poor natural ventilation. In contrast, Class 1 ($\lambda_{f(z)} \leq 0.35$) indicates that $VR_{w,j}$ may be larger than 0.2, which implies good natural ventilation (Ng et al., 2011).

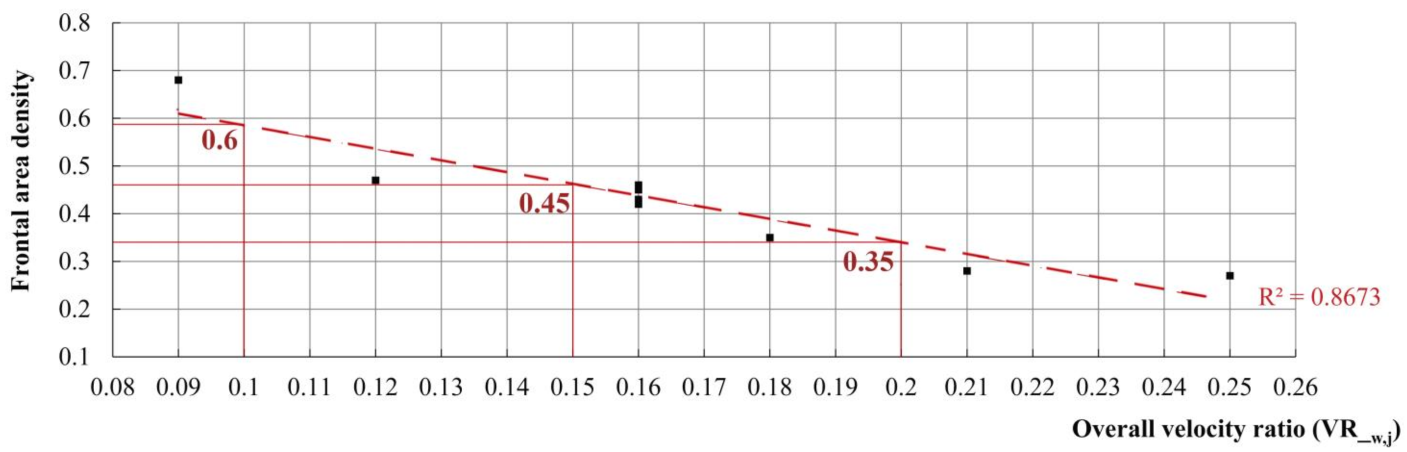

Figure 2 *Linear relationship between $\lambda_{f(z)}$ and $VR_{w,j}$ (Ng et al., 2011). The values of $\lambda_{f(z)}$ are classified as: (1) $\lambda_{f(z)} \leq 0.35$; (2) $0.35 < \lambda_{f(z)} \leq 0.45$; (3) $0.45 < \lambda_{f(z)} \leq 0.6$; and (4) $\lambda_{f(z)} > 0.6$.*

Modelling settings and result in Wu Han

To identify the value of 'z' in Equation (1), particularly in the context of Wu Han, this case study calculated the dividing level (27m) of the building height distribution (0m to 204m) using the local 3D building database in GIS. The urban morphology at the layer ranging from 0m to 27m is considered as being much denser than the layer ranging from 27m to 204m. Therefore, the value of 'z' in this case study is set to 27m.

To identify the local annual prevailing wind probability P_θ of Wu Han in Equation (2), the wind frequency data from Wu Han Observatory was used. The prevailing wind directions were identified as south ($\theta_1 = 90^0$), southeast ($\theta_2 = 135^0$), and southwest ($\theta_3 = 45^0$), and their frequency is generally similar. Therefore, the values of $P_{\theta,i}$ $(i = 1, 2, 3)$ across the three prevailing wind directions are simplified as $1/3$.

After calculating $\lambda_{f(z)}$ at resolution of 100m × 100m and classifying the results based on Figure 2, the urban permeability of the pedestrian-level natural ventilation in Wu Han is mapped as shown in Figure 3. Given the uncertainties in the modelling results caused by the linear regression analysis and other assumptions, the modelling results are considered as acceptable for the planning practices in the initial stages of the decision making process.

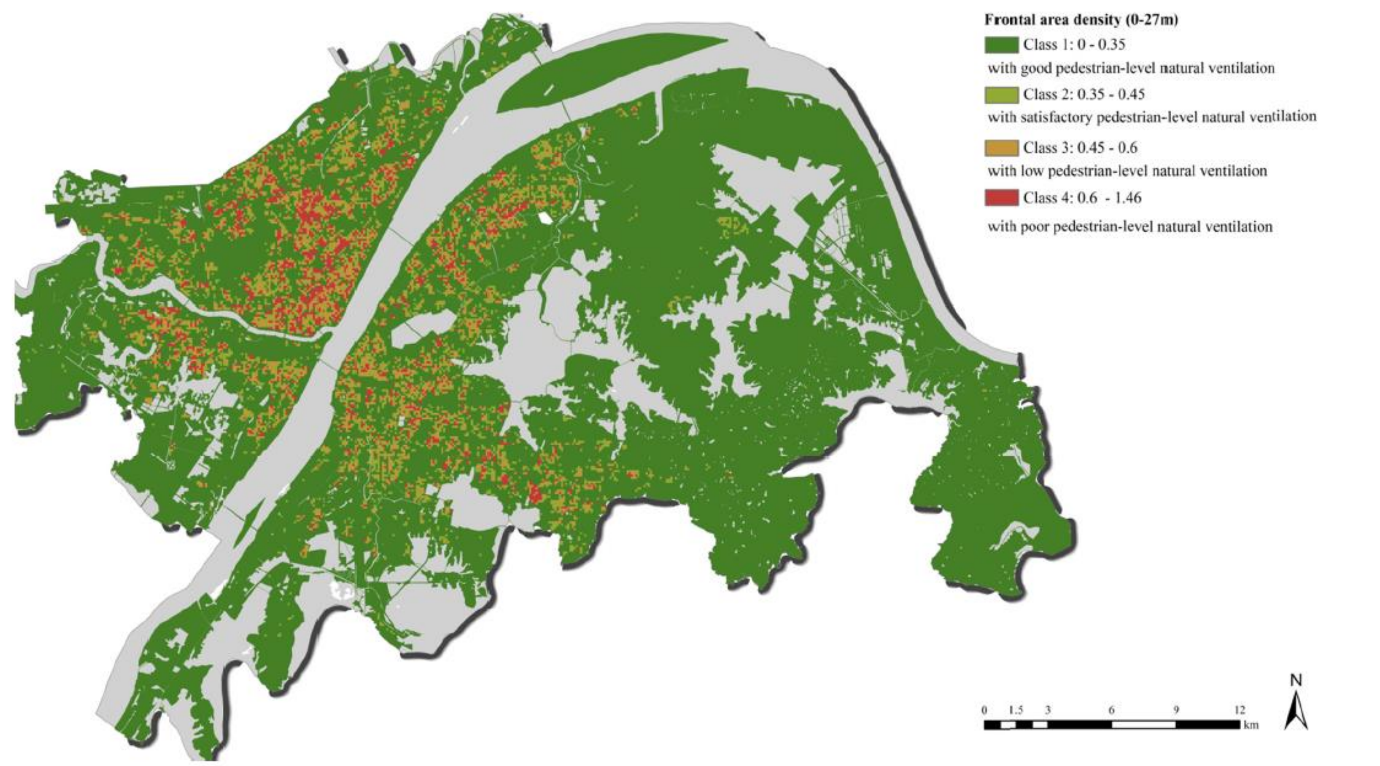

Figure 3 *Urban permeability map of the pedestrian-level natural ventilation in Wu Han. The values of $\lambda_{f(z)}$ were classified as: (1) $\lambda_{f(z)} \leq 0.35$; (2) $0.35 < \lambda_{f(z)} \leq 0.45$; (3) $0.45 < \lambda_{f(z)} \leq 0.6$; and (4) $\lambda_{f(z)} > 0.6$.*

IMPLEMENTATION IN URBAN PLANNING

The urban permeability map shown in Figure 3 provides urban planners with an intuitive grasp of the natural ventilation of urban areas for the master planning in which the district land use and density are determined. As shown in Figure 4, the lower urban permeability areas (Classes 3 and 4) include Hankou, Wuchang, and Hanyang, in the downtown area of Wu Han. It indicates that the airflow in the street canyon is seriously restricted by compact building blocks, and the outdoor natural ventilation may worsen in these areas. By contrast, the surface roughness in the other districts located far from the downtown area is still very low ($\lambda_{f(z)} \leq 0.35$). Compared with these districts in which new development is still acceptable, the urban density at Hankou, Wuchang, and Hanyang should be strictly controlled in the master plan, and particular mitigation strategies in the district planning for these three areas are also necessary.

Figure 4 *a): Potential air path I (urban scale). White dashed lines marks the boundaries of areas with low urban permeability in Hankou. Potential air path I were represented by blue hollow arrows. b): Potential air path II (neighbourhood scale). White dashed lines marked the boundaries of areas with low urban permeability in Hankou. Potential air paths II were represented by blue dashed line arrows.*

Based on the above analysis, district-based information is needed, which can be provided by the high-resolution urban permeability map, as shown in Figures 4a and 4b. The areas with low urban permeability occupy most of Hankou. Compared with Hankou, the urban permeability in Hanyang and Wuchang are relatively high. Furthermore, in Hankou, the areas with low urban permeability are wide and close to each other, whereas in Wuchang and Hanyang, they are smaller and more scattered. Correspondingly, different district planning goals and mitigation strategies are suggested in the respective districts:

1） Planning goals and mitigation strategies for Hankou

The planning goal for Hankou district is to identify the key areas to make the potential air paths play a role in encouraging the flow of fresh air into the deeper urban areas of the city. This strategy is more practicable than decreasing the urban density of the whole district because of the presence of wide urban areas with low permeability. According to the planning goal, the corresponding planning strategies are as follow:

• As shown in Figure 4a, the areas with low permeability are marked by white dashed lines. The gaps between these boundaries, represented by blue hollow arrows, are characterized by comparatively low surface roughness and are considered as the key areas for the potential air path I. The ground coverage ratio (λ_p) in these key areas needs to be strictly controlled to make sure air paths are connected to each other - that is, λ_p must be less than 30% (Yoshie et al., 2008). The width of the air path I range from several hundred meters to one kilometre.

• The air path II is in the neighbourhood scale, which is detected inside the low permeability areas and is represented by blue dashed arrows in Figure 4b. The potential air path II is important in the separation of single and wide low-permeability areas into smaller areas, so that the air can flow into them and thereby mitigate the high intensity of the urban heat island in these areas. The width of the air path II is about 100m. The values of λ_p at the air paths need to strictly be kept below 30% (Yoshie et al., 2008).

2） Planning goals and mitigation strategies for Wuchang and Hanyang

The low-permeability areas in Wuchang and Hanyang are scattered. As a result, the planning goal for these two districts is to decrease the urban density of the whole district, avoiding the spread of the small and scattered low-permeability areas. No mitigation strategies are viable in creating an air path in these two districts. Based on the above planning goal, the corresponding district planning strategies are as follow: the land use density of new development projects needs to be controlled by the ground coverage ratio (λ_p), which must be less than 50%, or better yet less than 30%.

CONCLUSIONS AND LIMITATION

In wind tunnel experiments and CFD simulations, the air in the street canyon is treated as the control volume. By contrast, as a viable alternative, the morphological method is an empirical model based on the relationship between urban morphology parameters and experimental wind data. Because of this characteristic, the complicated calculations associated with fluid mechanics can be avoided during the planning process, by using morphological method. Urban planners can easily relate the urban natural ventilation knowledge to the urban planning parameters, by using the local 3D building database.

This case study of Wu Han highlights the practical application of the morphological modelling method, from modelling, to the analysis of results, to the establishment of planning guidelines for both master and district planning. As our knowledge of roughness parameters improves and as more experimental data becomes available, the morphological modelling method can be more convincing and has the potential for broader application

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Comparing deterministic and probabilistic non-operational building energy modelling

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ABSTRACT

There is a lack of consensus about whether researchers and practitioners should use a deterministic single value or probabilistic distribution of values for each input when modelling the life cycle of a building. This study produces a direct comparison of the two approaches by modelling the non-operational life cycle energy of three buildings deterministically and probabilistically to explore whether the two approaches produce different conclusions. A detailed method describes the model - its structure, formulae and the best-case, typical and worst-case inputs - with supporting references. This detail provides a thorough explanation of why probabilistic modelling suggests that non-operational energy could be 28-44% lower or 48-283% higher than the original values and why a significant shift in the distribution of non-operational life cycle energy is possible. When used deterministically, the model suggests non-operational energy use is greatest during the product phase. However, when used probabilistically, the model highlights the risk that short component lives and long distance transport by road can significantly increase non-operational energy during the use, construction and end of life phases. The study discusses how future modelling should address a number of uncertainties so that it is more useful for researchers and practitioners.

INTRODUCTION

Reducing occupant demands for the operational energy used to heat, cool, light and ventilate buildings is currently the narrow focus of building regulations all over the world. However, there is increasing interest in a better understanding of the 'non-operational' environmental impacts of buildings that occur between the extraction of raw materials and their disposal, incineration or recovery.

One technique that researchers and practitioners use for this purpose is life cycle assessment (LCA) and there are now emerging standards that adapt the general principles of LCA (detailed in ISO 14040) to buildings. In theory, these standards should ensure greater consistency and fairer comparisons of compliant studies, but they still require users to make a number of important choices. One such choice is whether to use a deterministic single value or probabilistic distribution of values for each input when

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modelling the life cycle of a building. Studies can currently adopt either of these approaches and still be compliant with the standard, which reflects the current lack of consensus among researchers and practitioners about whether the two approaches are equally valid.

A deterministic approach to LCA and specifically life cycle energy is currently the norm. This is indicated by the precise results discussed by a 2010 review of building life cycle energy (Ramesh, Prakash, & Shukla, 2010), but also by the fact that the latest LCA software for practitioners only allows users to input a single value for multiple assumptions. However, a probabilistic approach to LCA also has its advocates that argue a deterministic approach is unrealistically precise (Fawcett, Hughes, Krieg, Albrecht, & Vennström, 2012). They cite how life cycle costing (LCC) uses probabilistic (or 'stochastic') models (which is evidenced by (Korpi & Ala-Risku, 2008)), but this does not seem to have influenced the approach to LCAs of buildings.

The lack of consensus among life cycle assessors suggest that a direct comparison of the deterministic and probabilistic approaches to building life cycle assessment modelling would also be a useful contribution to knowledge and would have numerous precedents. Others have undertaken many deterministic and probabilistic modelling comparisons for a variety of phenomena.

Aim

The aim of this study is to undertake a direct comparison of the deterministic and probabilistic approaches to building life cycle modelling by probabilistically modelling three building LCAs that were originally modelled deterministically. The focus is non-operational life cycle energy (primary) as it is consistently and comprehensively dealt with by existing building LCAs (Khasreen, Banfill, & Menzies, 2009). However, the following method could apply to other environmental impacts too.

METHOD

The method comprised four steps. The first step was to design a comprehensive, but concise modelling process that was compatible with the relevant building LCA guidance as well as both deterministic and probabilistic approaches. The second step was to select three deterministic building LCAs and reproduce their results, thereby establishing confidence in the model as well as clarifying the original values used for each model input. The third step was to select reasonable best-case, typical and worst-case values as an approximate probability distribution for each model input. The fourth and final step was to compare the one result - produced with the set of original values - of the deterministic approach and the three results - produced with the sets of best-case, typical and worst-case values - of the probabilistic approach.

Designing the model - its structure, formulae and scope

The model is process-based and can accept a three-point estimation of the probability distribution for each input. It breaks down the building life cycle into phases and modules according to the standard EN 15978, and the building fabric into components based on the New Rules of Measurement (NRM) (RICS, 2012). The way it calculates non-operational life cycle energy is also compatible with EN 15978 guidance, but several other sources were also consulted to understand emerging conventions not currently covered by the standard (Adalberth, 1997; EeBGuide, 2012; Moncaster & Symons, 2013). More specifically, the model generates the non-operational building life cycle energy of a building from the sum of the product phase energy, construction phase energy, use phase energy and end of life energy for the *n* different materials in the building:

$$E_{build} = \sum_{m=1}^{n} E_{pro,m} + \sum_{m=1}^{n} E_{con,m} + (A \times C_{in}) + \sum_{m=1}^{n} E_{use,m} + (A \times C_{un}) + \sum_{m=1}^{n} E_{end,m} \qquad (1)$$

The model defines each of the terms in Eq. (1) as follows:

$$E_{pro,m} = M_{ini,m} \times C_{pro,m} \times P_{pro} \quad (2)$$

$$E_{con,m} = \left(M_{ini,m} \times D_{con} \times C_{tra}\right) \quad (3)$$

$$E_{use,m} = M_{rec,m}\left(C_{pro,m} + (D_{con} \times C_{tra}) + (D_{end} \times C_{tra}) + C_{dis,m}\right) \quad (4)$$

$$E_{end,m} = \left(M_{ini,m} \times D_{con} \times C_{tra}\right) + \left(M_{ini,m} \times C_{dis,m}\right) \quad (5)$$

$$M_{ini,m} = M_{des,m} \times (1 + W) \quad (6)$$

$$M_{rec,m} = \sum_{p=1}^{4} M_{ini,m} \times M_{p,m} \times \left\lceil \frac{Y_{build}}{Y_{p,c}} - 1 \right\rceil \quad (7)$$

Note that it is crucial to assign materials to different components so that it is possible to establish the quantity of recurring material from the quantity of initial material using Eq. (7). Note also that Eq. (7) rounds up the number of times each component is maintained, repaired, replaced and refurbished during the life of the building (which EN 15978 refers to as modules B2-B5). Eq. (4) enables a comprehensive assessment of the non-operational energy used during all four of these processes between obtaining the recurring materials and treating them at the end of life. The obvious omission from Eq. (4) is the use of machinery during installing and uninstalling, which requires further study.

Selecting deterministic studies and reproducing them with the model

Analysis of the building life cycle energy studies summarised by two recent review articles (Ramesh et al., 2010; Yung, Lam, & Yu, 2013), highlighted 20 cases for closer examination. This examination revealed that it was not possible to reproduce 15 of the cases, because they did not provide a detailed breakdown of material quantities. Of the remaining five, three offered the most comprehensive scope and explicit assumptions for reproduction by this study. Table 1 briefly summarises basic information about these three chosen cases and highlights the different building types and locations.

Table 1. Basic Information about the Three Cases

No.	Reference	Type	Location	Area (m^2)	Life (years)*
1	(Kofoworola & Gheewala, 2009)	Office	Thailand	60,000	50
2	(Scheuer, Keoleian, & Reppe, 2003)	University	USA	7,300	75
3	(Gustavsson, Joelsson, & Sathre, 2010)	Apartments	Sweden	3,374	50

* Case 3 also modelled an 'actual' life of 100 years, but 50 years is a more likely 'design' life

Table 2. Life Cycle Phases and BS 15978 Modules Considered by the Three Cases

Phase	EN 15978 Modules	Case 1	Case 2	Case 3
Product	A1-A3	Yes	Yes	Yes
Construction	A4	Yes	Yes	No
Construction	A5	Yes	Yes	Yes
Use	B2-B5	B4-Partial*	B4-Partial*	No
End of Life	C1	Yes	Yes	Partial
End of Life	C2	Yes	Yes	No
End of Life	C3&C4	Partial	Partial	Partial
Beyond	D	Partial	No	Partial

* Transport from factory gate to site and site to waste treatment facility not considered

Table 3. Building Components and NRM Elements Considered by the Three Cases

Components	NRM Elements	Case 1	Case 2	Case 3
Envelope	2.5 & 2.6	Yes	Yes	Yes
External Works	8	Partial	No	No
Internal Finishes	3	No	Yes	Yes
Fixtures/Fittings	4	Partial	Yes	Yes
Services	5	No	Yes	No
Substructure	1	Yes	Yes	Yes
Superstructure	2.1,2.2 & 2.3.1	Yes	Yes	Yes
Temporary Works	-	Unclear	Unclear	Unclear

Table 2 and Table 3 provide more detail about the scope of each study in relation to EN 15978 modules and NRM components. Case 1 and Case 2 combine the end of life modules C3-C4 (processing and disposing of waste) with module D (benefits beyond the life of the building). This means that they consider the energy saved by recycling or incinerating materials as a reduction in the life cycle energy of the building, which is actually contrary to EN 15978. In order to avoid confusion, this study does not model modules C3, C4 or D. Consequently, $C_{dis,m}$ is zero in Eq. (4) and Eq. (5). Table 4 and Table 5 identify and compare the original values used by the three cases. Table 4 summarises values that apply to all of the n materials. Table 5 summarises a few of the values for the production phase coefficient C_{pro} of specific materials used by the three cases. The table also compares them with typical values from the University of Bath (UoB) Inventory of Carbon and Energy (ICE) (Hammond & Jones, 2011) used subsequently for the probabilistic modelling.

Table 4. Original Values the Three Cases Used

Term	Full Description	Unit	Case 1	Case 2	Case 3
L_{build}	Assumed life of the building	Years	50	75	50
C_{con}	Coefficient for installing energy	MJ/m^2	300*	337	288
C_{dec}	Coefficient for uninstalling energy	MJ/m^2	52*	350	36
C_{tra}	Coefficient for transporting energy	MJ/kg/km	0.0027	0.0023*	-
D_{con}	Distance from factory to site	km	50*	75	-
D_{end}	Distance from site to waste facility	km	50	50*	-
W	Waste generated during construction	%	6*	5*	5*

* Inferred approximate or average values rather than values explicitly stated in the case studies

Table 5. Original Production Phase Coefficients C_{pro} (in MJ/kg) from the Three Cases and ICE

Material	Case 1	Case 2	Case 3*	ICE Typical Value	ICE Range (%)
Aluminium	216.50	207.00	-	155.00	+/- 20
Brick	1.86	2.70	-	3.00	+/- 30
Concrete	1.30	Unclear	1.45	0.75	+/- 30
Glass	17.10	6.80	14.84	15.00	+/- 30
Sand	0.10	0.60	-	0.10	Unclear
Steel	11.10 - 22.10	12.30 - 30.60	29.43	9.40 - 35.40	+/- 30
Wood	-	10.80	7.28	7.11	Unclear

* Inferred from end-use energy in kWh/tonne assuming an energy conversion efficiency of 0.5

Selecting the sets of best-case, typical and worst-case values

A literature review produced the best, typical and worst values in Table 6 used for all of the n materials in all three cases. (Although the model could accept a specific value for each material, it would then become hard to document it concisely.) Table 7 shows the best, typical and worst values used for calculating the replacement period Y_p for each component c. The values used for C_{pro} were specific for each material m and are the "typical" values from the ICE (Hammond & Jones, 2011) unless a more specific value was obviously appropriate. A percentage modifier P_{pro} in Eq. (2) enabled modelling of the general range associated with ICE values.

Table 6. Values this Study Uses

Term	Unit	Best Value	Typical Value	Worst Value	Supporting Reference(s)
C_{con}	MJ/m^2	20	300	750	(Gustavsson et al., 2010; Scheuer et al., 2003)
C_{dec}	MJ/m^2	10	300	900	(ATHENA, 1997; Gustavsson et al., 2010)
C_{tra}	MJ/tonne km	0.0004	0.0010	0.0020	(IPCC, 1996)
D_{con}	km	50	300	500	(EeBGuide, 2012)
D_{end}	km	50	300	500	(EeBGuide, 2012)
M_p	%	100	100	100	-
P_{pro}	%	70	100	130	(Hammond & Jones, 2011)
W	%	0	5	10	(Adalberth, 1997)

Table 7. Values this Study Uses for the Replacement Periods Y_p (in years) of each Component c (Supporting Reference (BCIS, 2006))

Component	NRM Elements	Best Value	Typical Value	Worst Value
Envelope	2.5 & 2.6	50	40	30
External Works	8	40	30	20
Internal Finishes	3	30	20	10
Fixtures/Fittings	4	30	20	10
Services	5	30	20	10
Substructure	1	90	60	30
Superstructure	2.1,2.2 & 2.3.1	90	60	30

With values for all inputs identified, it was possible to model the three cases with the original, best, typical and worst values. Note that all of the modelling was faithful to the scopes of the three cases (Table 2 and Table 3) and did not attempt to standardise them.

RESULTS

Table 8 summarises the results of reproducing the three cases. Figure 1 compares modelling the non-operational life cycle energy of the three cases with the original, best, typical and worst values.

Table 8. Deterministic Results of the Three Cases and their Reproducibility with the Model

Case	Phase	EN 15978 Modules	Original Result (TJ)	Reproduced Result (TJ)	Model Simplifications and Plausible Explanations for Discrepancies
1	Product	A1-A3	375.0	375.8	Modelled using one value for W
1	Construction	A4	Unclear	21.4	-
1	Construction	A5	Unclear	18.0	-
1	Use	B2-B5	Unclear	60.8	-
1	End of Life	C1	3.1	3.1	-
1	End of Life	C2	6.8	21.4	See the end of the discussion section
1	End of Life	C3&C4	Unclear	-	-
2	Product	A1-A3	39.3	40.7	Approximated M_{ini}
2	Construction	A4	2.5	2.5	Modelled using one value for C_{tra}
2	Construction	A5	2.4	2.5	Rounded up 2.46 TJ to 2.5 TJ
2	Use	B2-B5	6.9	5.0	Approximated M_{rec}
2	End of Life	C1	Unclear	2.6	-
2	End of Life	C2	Unclear	1.6	Modelled using one value for C_{tra}
2	End of Life	C3&C4	-	-	-

2	Other	C1&C2	4.0	4.2	-
2	Other	A1-A3&B4	46.3	45.7	Ignored materials under 1 tonne
3	Product	A1-A3	10.9	15.0	See the end of the discussion section
3	Construction	A4	-	-	Out of original scope
3	Construction	A5	1.0	1.0	-
3	Use	B2-B5	-	-	Out of original scope
3	End of Life	C1	0.1	0.1	-
3	End of Life	C2	-	-	Out of original scope
3	End of Life	C3&C4	-	-	Out of original scope

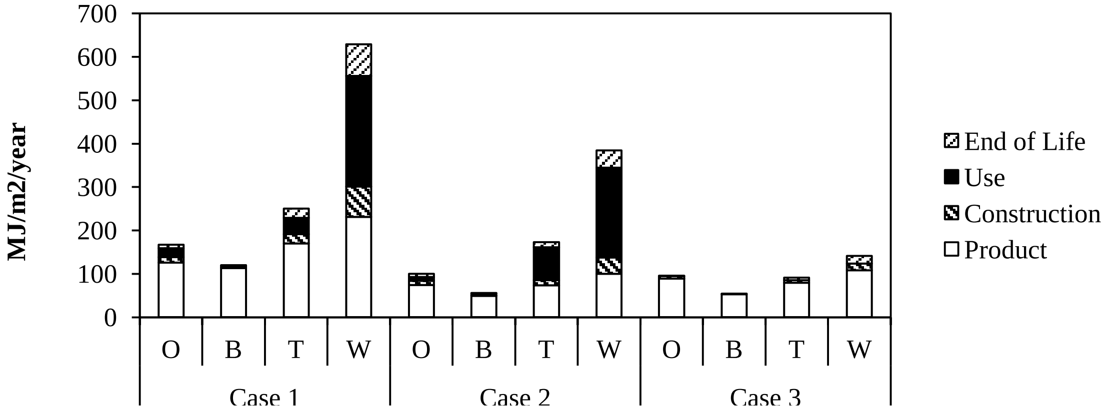

Figure 1 *A non-operational life cycle energy comparison of the three cases (1-3) modelled using the original (O), best (B), typical (T) and worst (W) values*

DISCUSSION

Figure 1 shows the difference between the one result - produced with the original values - of a deterministic approach and the three results - produced with the best, typical and worst values - of a probabilistic approach. Modelling with the original values appears optimistic in the context of the results produced with the other three sets of values and it is clear that the best and worst values highlight a significant opportunity and risk associated with the minimum and maximum quantities of non-operational energy. Compared to the original value results, the best value results are 28-44% lower while the worst value results are 277-283% higher for Case 1 and Case 2 and 48% for Case 3. The use phase non-operational energy for Case 1 and Case 2 notably increases dramatically with the worst values (by a factor of 13 and 23 respectively). The worst value results suggest that the total non-operational energy could represent as much as approximately 8% and 17% of the total life cycle energy of Case 2 and Case 1 respectively (based on actual operational energy data) and 12-22% of Case 3 (based on modelled operational energy scenarios and even though the use phase is out of scope).

Based upon the original values, the discussions and conclusions of Case 1 and Case 2 logically focussed on energy use during the operation and product phases while Case 3 focussed specifically on energy *sources* during the operation and construction phases. However, it is noticeable that all three cases suggested only a few practical actions to reduce non-operational energy use. Case 1 and Case 2 mentioned increasing recycled content, while Case 3 concentrated on substituting biomass for fossil fuel. Only Case 2 highlighted the possibility that frequent renovations could increase and shift the distribution of life cycle energy. The probabilistic modelling undertaken here suggests that practitioners should also consider the risk of short component replacement periods during the use phase and long distance transport by road during the construction and end of life phases. Probabilistic modelling is clearly useful to highlight the model inputs that produce significant uncertainty, but it is important that future research considers how an understanding of these sensitive model inputs translates into robust design decisions. Close collaboration between researchers and practitioners could be necessary.

Probabilistic modelling is obviously less useful when there is high certainty about the sensitive inputs. However, it is important to note that even though Case 1, 2 and 3 were all assessed after they were constructed, they mention numerous challenges of obtaining every detail about a building and how it was built. This suggests assessors should be cautious not to overestimate certainty. They could find probabilistic modelling useful not just for prospective, but also retrospective assessment.

Exploring uncertainties with future studies

The choice of scope in all three cases appears more important with probabilistic modelling than with deterministic modelling. Case 3 ignored the use phase completely while Case 1 and 2 ignored modules B2, B3 and B5 (the processes of maintaining, repairing and refurbishing) as well as all transportation. The results suggest that building LCAs should aim to be complete and imprecise rather than incomplete and precise. There is an argument that the standard EN 15978 should mandate a minimum scope of life cycle phases, modules and building components to reduce the variations in Table 2 and 3. While adopting this comprehensive scope, future building LCAs should also model different building types, constructed from different materials with context specific model inputs. These LCAs should continue to question transport distances from factory gate to site D, the building life Y_{build}, all use phase process periods Y_p and material replacement quantities M_p. They could test the logic of the different versions of Eq. (7) found in the literature and consider if and how different possible futures (changing practices, regulations, technologies) could affect the values in Table 6. This will require a more complex probabilistic modelling process and an appropriate approach to sensitivity analysis.

Learning from reproducing the three cases

A challenge of adopting a more complex modelling process is to still provide the information required to enable others to examine, reproduce, critique and improve it. (Although researchers could consider publishing whole models not just their research data.) The method of this study contains a number of tables that others could find useful to concisely provide the detailed description necessary, but they must also include (or reference) material quantities by component (see the matrix included in Case 3). Without this information, the reasons for the small discrepancies in Table 8 are unclear, but it is likely that they result from the original studies using specific values for each material rather than one average value for all materials unless otherwise stated. The significant discrepancies that resulted when modelling Case 1 Module C2 (transport from site to treatment facility) and Case 3 Modules A1-A3 (the whole product phase) are easier to explain. Case 1 originally assumed that the building generated only 0.845 t/m2 of waste, but the model assumes the transportation of all material to a waste treatment facility. Case 3 was only explicit about the production phase energy coefficients C_{pro} used for a few materials, so the model had to adopt appropriate typical values from the ICE instead.

CONCLUSION

A comprehensive, but concise building life cycle model was introduced and used to reproduce the non-operational energy of three buildings deterministically (based on the original information or assumptions) and probabilistically based upon a literature review of best, likely and worst values. When used deterministically, the model suggests non-operational energy use is most significant during the product phase. However, when used probabilistically, the model highlights the risk that short component lives and long distance transport by road can significantly increase non-operational energy during the use, construction and end of life phases. The formulae and literature review of plausible ranges for each model input presented here should facilitate probabilistic modelling in the future. They provide the basis for others to model different building types, constructed from different materials with context specific probability distributions for each model input that are based upon a better understanding of what happens in reality.

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NOMENCLATURE

A	=	floor area of the building	M	=	quantity of material
C	=	conversion factor	P	=	production phase ‘modifier’
D	=	distance	W	=	waste
E	=	non-operational energy	Y	=	life or period of time

Subscripts

build	=	building	*m*	=	material
c	=	component	*n*	=	number of materials
con	=	construction phase	*p*	=	use phase process
des	=	design	*pro*	=	product phase
dis	=	disposal	*rec*	=	recurring
end	=	end of life phase	*un*	=	uninstalling
in	=	installing	*use*	=	use phase
ini	=	initial			

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CBD greening and Air Temperature Variation in Melbourne

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ABSTR ACT

Melbourne, the second most populous city in Australia, is growing rapidly. To accommodate this growth, CBD area is undergoing dense urban development and consequently the microclimate of the city is affected. Understanding how greenery can influence the air temperature is very important in urban planning. This study presents a simulation approach to examine the impact of CBD greening on the air temperature variation, during a summer day in Melbourne. The numerical simulation system, ENVI-met was used to examine the impact of vegetation on the air temperature in CBD area, under various scenarios. Three scenarios were applied; without any vegetation, with the existing trees (2%), and enhanced number of the trees (6%). The simulation results showed significant lower air temperatures in both greening scenarios compared to the base case scenario without any vegetation. Increasing 4% tree coverage in the study area, led to 0.2 C° reduction in the air temperature. The study also found that the maximum cooling effect, occurs at mid afternoon. The outcomes of this study could be used to assist urban planners in developing policy suggestions for improving Melbourne's microclimate and offsetting the likely temperature impacts from increasing urban densities.

INTRODUCTION

Consistent population growth and urban development have triggered high demand for built environment and migration of people from rural to urban areas. According to Australian bureau of statistics, population of Melbourne has been increased by 9.7% from 2006 to 2011 (Australian Bureau of Statistics 2000). To accommodate this population growth, natural landscapes and vegetated areas have been replaced by impervious surfaces of buildings and pavements, leading to an alteration in the radiative, thermal and aerodynamic characteristics of the urban surfaces (Morris, Simmonds & Plummer 2001). One of the most significant consequences of the urbanization, is the temperature difference between the urban and rural areas, known as "urban heat island" (Oke 1984). The phenomenon, is mainly a result of high thermal capacity and heat storage of urban surfaces, anthropogenic heat, caused by human activities and reduced rate of evapotranspiration in urban areas (Oke 1988). The temperature rise in cities might be beneficial during winters, but it increases the energy demand and health risks during the summer (Yu & Hien 2006).

Melbourne, with a population over 3.6 million, features UHI consistently throughout the year (Morris, Simmonds & Plummer 2001). In 1992, an automobile transect across the city monitored 7.1C° temperature difference between the central business district (CBD) and surrounding suburban areas, with smaller peaks in industrial areas and the medium-density terrace housing in the inner northern suburbs (Torok et al. 2001). According to CSIRO (2011), the average daytime air temperature in Melbourne tends to rise from15.7 C° to 18.5 C° by 2070. Consequently, the number of the days with maximum air temperature will be increased. A study by Lynch et al. (2011) states that, the mortality rate is likely to be doubled by the latter part of the current century. Four days heat wave in Melbourne was resulted in 374 excess deaths in January 2009. The mortality rate is often maximum among among elderly and people with respiratory diseases (Victorian Department of Human Services 2010). Therefore, the process of urbanization and temperature rise in Melbourne city, presents a clear issue for public health, sustainability of urban environments and thermal condition of the city, particularly during hot seasons.

Microclimatic benefits of vegetation have been extensively investigated in previous researches (Avissar 1996; Huang et al. 1987; Jauregui 1991; Oke et al. 1989; Shashua-Bar & Hoffman 2000). Vegetation not only provides pedestrians with pleasurable visual scenes, but also provides shading, improves air quality, reduces the noise levels and contributes to the mitigation of the urban heat island effect (Dimoudi & Nikolopoulou 2003). Over 25-50% mitigation of heat island intensity can be achieved through greening strategies (Rowntree, Sanders & Stevens 1982). Various greening strategies have been used to reduce the air temperature and the level of air and noise pollution, such as, green roofs, urban parks, trees, shrubs and grass (Oliveira, Andrade & Vaz 2011). The cooling effect of vegetation occurs through the process of shading, evapotranspiration and changing the wind pattern. The average cooling effect of vegetation is between 1 to 4.7 C°, that can be extended by 100 to 1000 meter radius around the vegetated area. The cooling effect also highly depends on the available water for irrigation (Schmidt 2006).

Over the last decade, several studies have been conducted in various climatic condition, to investigate the detailed relationship between different greening scenarios and urban microclimate (Lin, Matzarakis & Hwang 2010; Ng et al. 2012; Shashua-Bar et al. 2010; Wong et al. 2007), but the number of the number of these studies in Australia is lacking. Therefore, this study aims to examine the effect of different greening scenarios on the air temperature variation in Melbourne, by using a numerical modeling system, ENVI-met.

Many methods have been applied to investigate the effect of vegetation on microclimate, such as numerical modelling (Avissar 1996; Pearlmutter, Krüger & Berliner 2009; Spronken-Smith & Oke 1999), empirical analysis, on site measurement (mobile traverse, weather station data) (Jonsson 2004; Sani 1987; Upmanis, Eliasson & Lindqvist 1998) and satellite images (Ooka 2007). But, numerical modeling has become more popular than on-site field measurements during recent years. Because researchers have greater control over modeling in regards to the time and resources (Arnfield 2003). Additionally, numerical models are capable of coping with the complexities and non-linearities of urban structures.

Some recent studies used three-dimensional numerical model, ENVI-met to simulate the effect of vegetation on microclimate (Ali-Toudert & Mayer 2007; Fahmy & Sharples 2009; Fahmy, Sharples & Eltrapolsi 2009; Spangenberg et al. 2008; Yu & Hien 2006). ENVI-met, simulates the microclimatic changes within urban environments in a high spatial and temporal resolution (Bruse & Fleer 1998). It can also calculates all important meteorological parameters, such as the solar radiation, air temperature, relative humidity, wind speed, as well as the mean radiant temperature. Buildings, overhangs, galleries and setbacks can be illustrated via ENVI-met (Hedquist et al. 2009).

This study, uses numerical simulation model, ENVI-met (Bruse M 2011a) to generate the air temperature data for the central business district area, and to examine the effect of different greening scenarios on the air temperature variation in a typical urban environment in Melbourne's CBD. Three scenarios are examined; a base case scenario without any vegetation, scenario "1" with existing trees in the site which cover 2% of the study area and scenario "2" with uniformly enhanced trees, placed at the fixed distance from each other, which cover 6% of the study area. Table 2 lists the detailed characteristics of each scenario.

METHODOLOGY

Melbourne, is the capital and most populous city in the state of Victoria, and is the second most populous city in Australia. Geographical coordinates of Melbourne are (37°49′S, 144°53′E) and according to Köppen climate classification, Melbourne has a moderate oceanic climate. The city has been well reputed for its unstable weather condition (Sturman & Tapper 2006). Melbourne summers are notable for the occasional days of extreme heat (Bureau of Meteorology 2009). The highest temperature recorded in Melbourne city was 46.4 °C (115.5 °F), on 7 February 2009.

To investigate the impact of different greening scenarios on the air temperature, a typical urban environment was selected in the central business district area in Melbourne. The Hoddle Grid with the dimensions of 1.61 by 0.80 km, forms the center of Melbourne's central business district. Most of the buildings in this area are 8 to 12 storey and streets have 15 and 30 meter width. Figure 1, shows the boundary of the selected site.

Most of the studies using ENVI-met, conducted comprehensive field measurements to validate the outputs of the software with on-site measurement. Thapar and Yannas (Thapar & Yannas 2007), used field measurements to validate the findings of ENVI-met on the air temperature and wind variation around specific urban forms. Hedquist et al. (2009), used the software along with CFD and field measurements to report the temperature variation in high density areas.

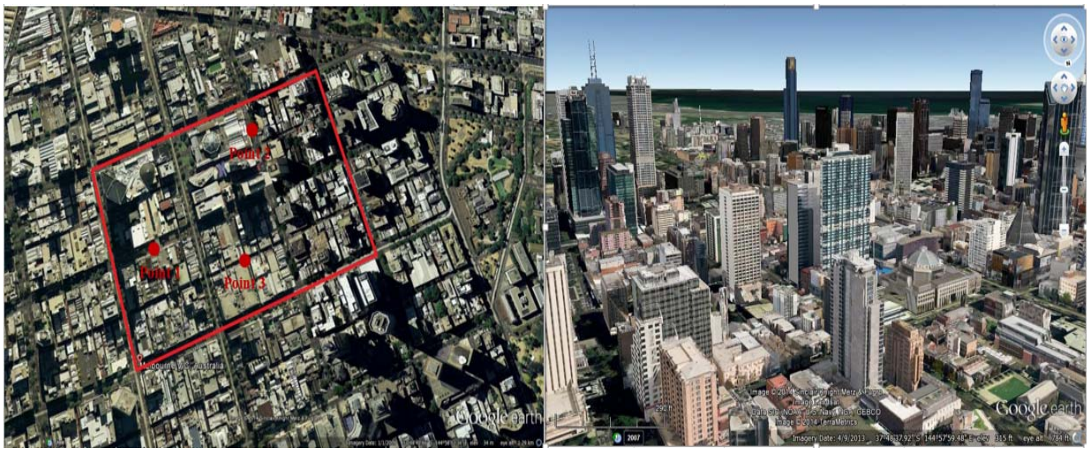


Figure 1. Boundary of the study area in central business district of Melbourne, Australia, Red color circles indicate the spot points for field measurements (Left) 3D view of the study area (Right)

In this study, three points were selected in the study area, to verify the results of the simulation with the on-site measurements. Hobo data loggers were used to monitor and compare the air temperature variation at the selected points. The location of each point is shown in Figure1. An ENVI-met model was first created, according to the exact urban geometry and vegetation coverage of the site. Climatic data, such as the initial air temperature, relative humidity, cloud cover and wind speed (19 December 2013) were initially given to the model, according to the data obtained from the "Australian Bureau of Meteorology". The model was then run for 24 hours, starting from 6 am and ending at 6 am the following day. The simulation results for the air temperature (Ta) were extracted, plotted and compared with the air temperature measured at the site, for four different times of the day; 9 am, 12 noon, 3 pm and 6 pm. These periods of the time were selected, because they cover the times when the temperature is minimum, when it reaches to its maximum and when the temperature begins to drop. Comparison between the measured values and simulated data was made by conducting a regression analysis. Figure 2, shows a reasonable agreement between the measured and simulated data, with R value of 0.8. The usefulness of ENVI-met in predicting the air temperature variation, in Melbourne's urban environment during summertime was therefore confirmed. The verified simulation settings are given in Table 1. These settings were then applied in simulating different scenarios.

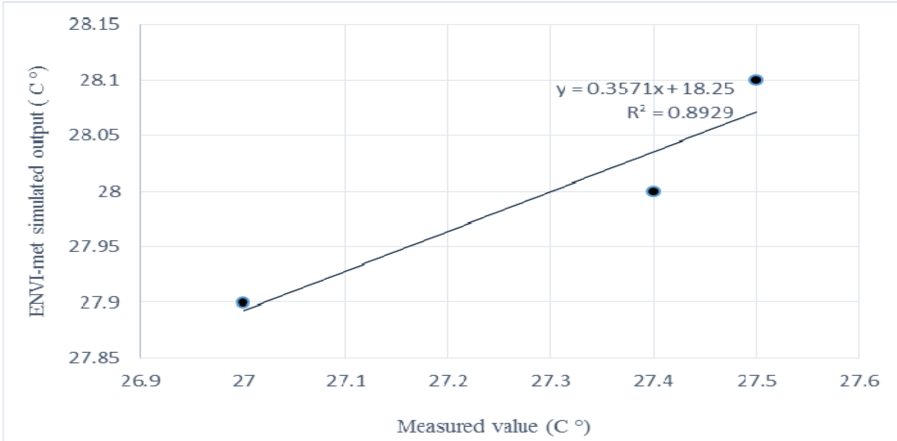


Figure 2 Comparison of the averaged measured and simulated air temperatures (Ta) in 19 December 2013

Table 1. Verified ENVI-met simulation settings

Time	Initial Temperature	Start Time	Relative Humidity at 2 m (%)	Wind Direction	Wind Speed at 10 Meter level (m/s)	Albedo of the Roofs	Albedo of the Walls
19 December 2013	300.5 K	6 :00 am	49%	North	15	0.3	0.2

One approach in urban climate modeling, is simplifying the complex urban structures into generic urban layouts, in order to understand the effect of altering a certain parameter in a system (Robinson et al. 2007). This method is also applicable in modelling the global climate, economic or ecological systems, as well as in biology and health studies. Therefore, to understand the impact of trees on the air temperature variation, a generic layout of the selected site was created. Climatic data and geographical features of the site, such as the average building height (30 meter) and the widths of the streets (15, 30) were given to the model. Mature 20m dense distinct crown trees were used in the model. A snapshot of the generic urban layout of the study area was created by ENVI-met in Figure 3. The detailed inputs for configuration file is also presented.

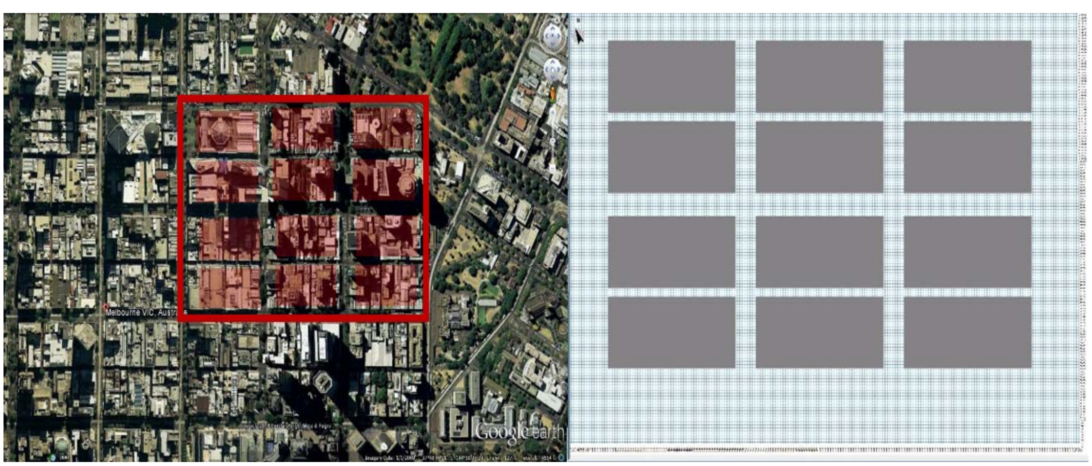
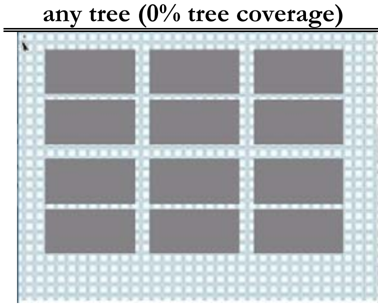
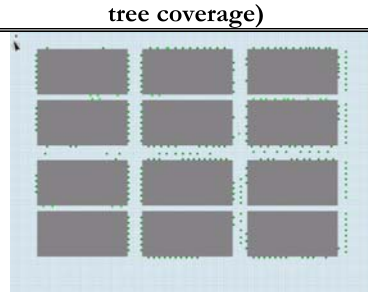
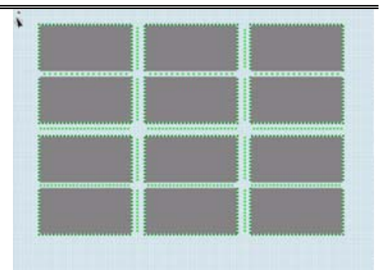


Figure 3 (Left) Aerial view of the study area (right) Snapshot of the ENVI-met model

Ariaepel % ---- Basic Configuration File for ENVI-met Version 3 ---------------
% ---- MAIN-DATA Block ---
Name for Simulation (Text): = Base Case Scenario
Input file Model Area =C:\Users\User\Desktop\paper 2\Base Case Scenario.in
Filebase name for Output (Text): =model 1 base
Output Directory: =C:\Users\User\Desktop\paper 2
Start Simulation at Day (DD.MM.YYYY): =19.12.2013
Start Simulation at Time (HH:MM:SS): =06:00:00
Total Simulation Time in Hours: =24.00
Save Model State each? Min =60
Wind Speed in 10 m ab. Ground [m/s] =15
Wind Direction (0: N...90: E...180: S...270: W...) =0
Roughness Length z0 at Reference Point =0.1
Initial Temperature Atmosphere [K] =300.5
Specific Humidity in 2500 m [g Water/kg air] =7
Relative Humidity in 2m [%] =49
Database Plants =C:\ENVImet31\sys.basedata\Plants.datFirst numbered item

Table 2. Different scenarios

Base case scenario, Without any tree (0% tree coverage)	Scenario 1, Existing trees (2% tree coverage)	Scenario 2, (6% tree coverage)
		

RESULTS AND DISCUSSIONS

A typical summer day, 19 December 2013 was simulated, using verified settings of the model (Table 1). The simulations were run on a core 2 quad processor 8 and GB of RAM. Each run took about 7 to 8 days.

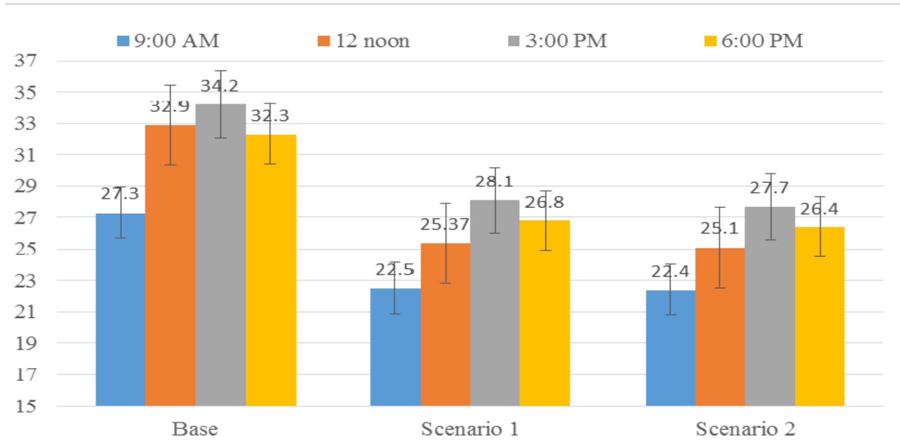
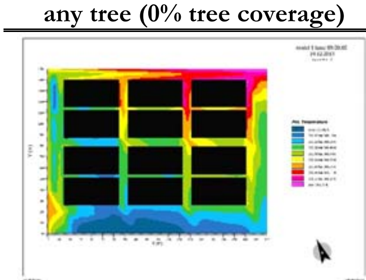
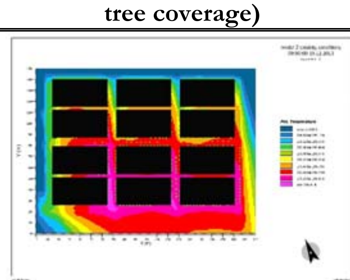
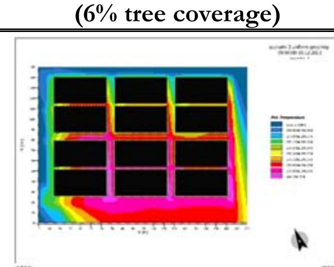
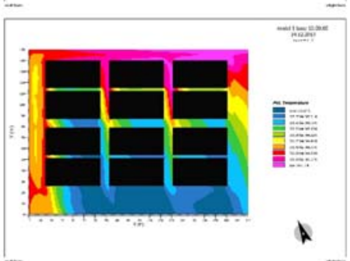
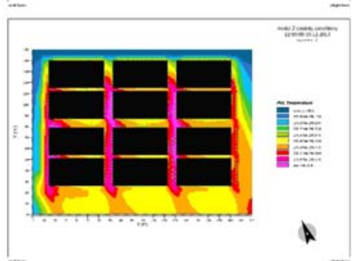
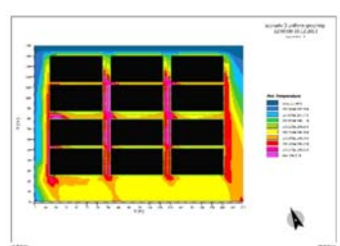
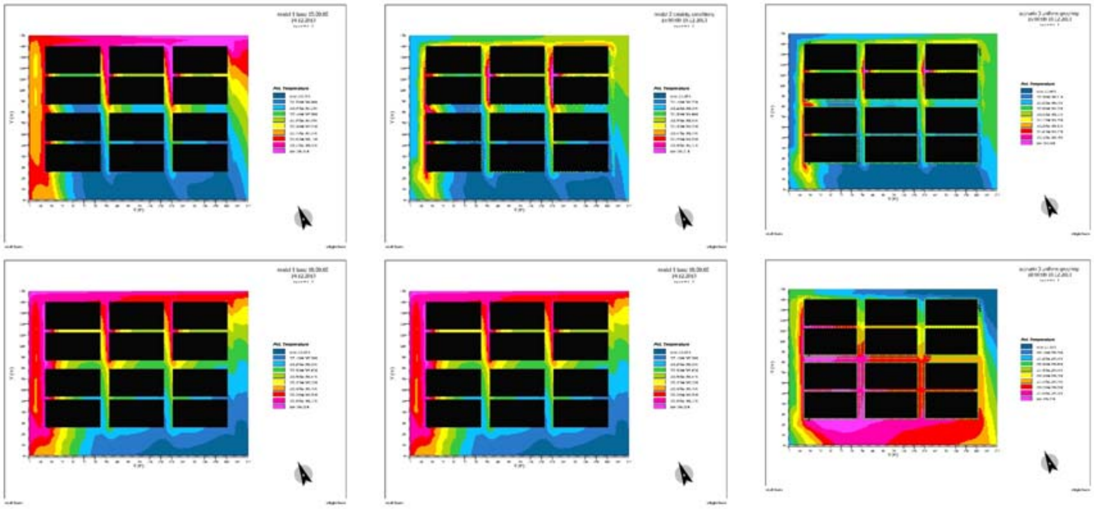


Figure 4 Variation of the air temperature in different scenarios

The results of the simulations for 9 am, 12 noon, 3 pm and 6 pm were extracted and analyzed. Figure 4, shows the variation of the air temperature in each scenario and Table 3 illustrates the LEONARDO images of the outputs for various scenarios, in different times of the day. Some preliminary findings can be derived from Figure 4 and Table 3. The main finding is that, both greening scenarios (existing trees and uniform enhancement of the trees) significantly modify the air temperature. The maximum level of modification occurs at 12 noon. Compared with the base case scenario without any tree, scenario 1, with the existing trees in the site contribute to 4.8 °C, 7.5 °C, 6.1 °C and 5.5 °C reduction in the air temperature at 9am, 12 noon, 3 pm and 6 pm respectively. The existing tree case (scenario1), can provide more shade, therefore, from the LEONARDO images, it can be seen that, under the trees, the reduction of the air temperature is more intense. Uniform enhancement of the tree (scenario 2) also decreases the air temperature, compared to the base case scenario. As Figure 4 shows, 4.9 °C, 7.8°C, 6.5 °C and 5.9 °C temperature difference is recorded between the base case scenario and scenario

Table 3. The spatial distribution of the air temperature in different scenarios at 9 am, 12 noon, 3pm and 6 pm (From top to bottom)

Base case scenario, Without any tree (0% tree coverage)	Scenario 1, Existing trees (2% tree coverage)	Scenario2, Uniform greening (6% tree coverage)
		
		



These results are in accordance with the findings of similar studies on the impact of city greening on the air temperature (Bowler et al. 2010; Yu & Hien 2006). In regards to the air temperature reduction caused by greening scenarios, the result of this study is comparable to Taipei study, which showed 0.81K temperature reduction caused by urban parks (Chang, Li & Chang 2007) and Singapore study, which monitored 1.3 K decrease in the air temperature, due to urban greening (Yu & Hien 2006). A general conclusion can be achieved that, urban greening in the forms of trees can provide cooling effect to the urban environment. LEONARDO images in Table 3, show that, the air temperature in deep canyons is slightly lower than the air temperature in shallow canyons. More shading in deep canyons and less exposure to the direct sun are the plausible explanation of slightly lowered ambient temperature in narrow canyons for most of the locations. Explanation for the smaller temperature difference between base case scenario and scenario 1 compared to the base case scenario and scenario2, relates to the lower level of tree coverage in scenario 1. Because in scenario1, the existing trees are quite sparse, in comparison with scenario 2 with uniform trees planted through the site. As Figure 5 indicates, the maximum temperature difference between the base case scenario and greening scenarios was monitored 12 noon.

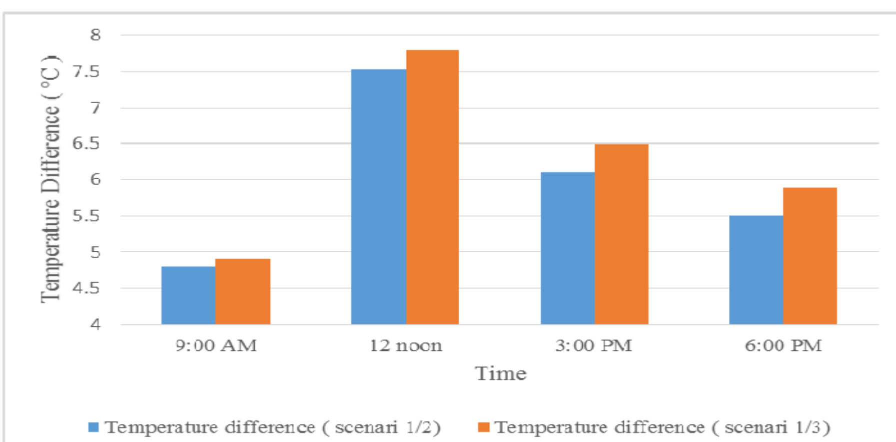


Figure 5 Temperature difference between greening scenarios at 9am, 12 noon, 3 pm and 6 pm

The findings of this study serve as a proof of concept to show how numerical microclimatic modeling can help to incorporate the urban greening schemes into CBD planning, urban development and visualize the potential cooling benefits of various greening and design scenarios. This study was limited to the impact of urban greening in the form of trees on the air temperature. However , the study aims to include the impact of urban parks, Australian native trees and leaf area index will be studied on the air temperature variation in Melbourne. Furthermore, the effect of building layouts, street orientation and urban layouts on the air temperature will be also addressed.

CONCLUSION

This paper presented a preliminary study on the cooling effect of street trees in the CBD of Melbourne. Numerical modeling system, ENVI-met was verified through conducting field measurements. Verified settings were applied to the model, to simulate the air temperature variation in a generic urban layout of the CBD. Three scenarios were simulated; a base case scenario without any vegetation, scenario "1" with the existing trees in the site (2% tree coverage) and scenario "2" with uniform tree enhancement (6% tree coverage). It is found that both greening scenarios, contribute to the significant air temperature reduction. The maximum cooling effect of trees was detected at 12 noon. The study also revealed that 4% increase in tree coverage would lead to 0.2 °C reduction in the average air temperature. This study demonstrates how the simulation approach can help urban planners to better understand, visualize and analyze the potential cooling effect of urban greening and design related strategies.

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Session 2A : Passive Design

PLEA2014: Day 1, Tuesday, December 16
14:10 - 15:50, Auditorium - Knowledge Consortium of Gujarat

Sustainable Habitat for Emerging Economies

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ABSTRACT

Affordance of thermal comfort, as a key to sustainable habitats in emerging economies, entails a socio-economically responsible response to the imperatives of local climate, low-energy, and lifestyle changes. Since passive house thermal comfort depends on occupant's lifestyle, low-energy architecture that integrates passive techniques and lifestyles becomes avant-garde. Thermal comfort is the absence of discomfort in the occupants mind because of the body's interaction with environment parameters: temperature, humidity, and air speed, which are enhanced by ventilation. Since socio-cultural lifestyle changes due to globalization and developments resulted in new notions of comfort and adaptation to heat producing equipments, lifestyle is recognize as essential to low-energy paradigms during operations, and heat loss or gain through appropriate ventilations and storage of heat or cold in high thermal mass envelopes could be beneficial. The case study, Bidani Eco-house in Faridabad by Dr. Arvind Krishan is a haveli[1] inspired plan form with appropriate open-spaces, orientation, or geometry, and envelope with low U-value local stones and glass facade, which are expected to reduce heating and cooling load if integrated with lifestyle. Research methods encompasses questionnaire with users, field survey, monitoring of hourly indoor temperature with data loggers, and a series of parametric simulations with Solar Designer ver. 6. The paper discusses passive techniques and lifestyles, through 1) indoor temperature fluctuation without air-conditioning to highlight the effects of ventilation modes, air change rates, and thermal mass on environmental comfort parameters, 2) comparative energy performance analysis of annual (2013) cooling, heating, and lighting load with GRIHA[2] benchmark to validate the successful integration of lifestyle and passive design. The house low-energy EPI (Energy Performance Index) of 126MJ/m^2/year shows that thermal comfort is affordable with relative low-energy in a rapidly changing cultural expectation of modern life.

INTRODUCTION AND BACKGROUND

This paper, essentially, reports "Sustainable Habitats for Emerging Economies" from the perspectives of "thermal comfort" afforded by the integration of passive design and lifestyle as a low-energy solution during operations. Thermal comfort, as a subjective response or state of mind, is primarily influence by the body's heat exchange with the environment parameters: temperature, humidity, air speed (Olesen & Brager, 2004), and corresponds to a temperature range of 20-30ºC DBT and 30-60% relative humidity in still air. (Govt. of India, Energy. n.d.). Personal parameters: clothing, activity, or metabolic rates are not covered in this report. Economic developments and socio-cultural lifestyle changes due to globalization resulted in new notions of comfort and adaptation to heat producing equipments, high energy use, and subsequent lost of the native habitats milieu. So, lifestyle is recognize as essential to low-energy operations. In India, lighting and household appliances such as: refrigerators, air conditions, water heaters, and ceiling fans accounts for 10% of electricity consumption,

1. Enclosed courtyard in private mansions in India and Pakistan.
2. An acronym for Green Ratings for Integrated Habitat Assessment, developed jointly by TERI and the Ministry of New and Renewable Energy, Government of India.

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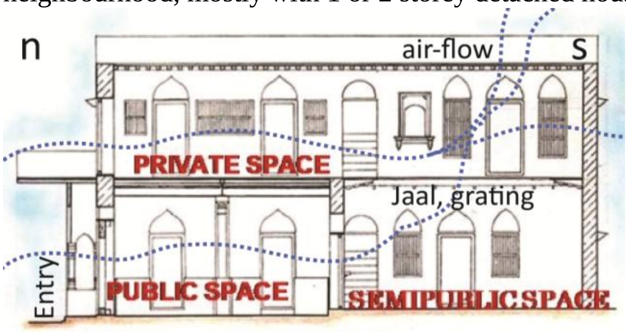
while housing and commercial sectors accounts for 29% of electricity consumption and rises at the rate of 8% annually. (Govt. of India Planning, 2011). In India, majority of the households are dependent on ceiling or table fans for cooling in summer, and air-conditioning use is relatively less. In view of the construction as the second largest economic activity (8%), and the projected urban population of about 600 million by 2030 (Govt. of India Planning, 2011), India's energy consumption during construction and operations is expected to increase, exponentially. This paper is limited to low-energy imperatives during operations, and doesn't cover full life cycle cost analysis for the construction period.

Traditional architecture manifests the local climate, lifestyle, and materials. Faridabad, located at coordinates: 28.9°N, 77°E; and 216m above mean sea level is in 'composite climate', with extreme climate swings: maximum DBT of 45°C for about 2 and half months, followed by hot-humid monsoon, and minimum DBT of 3°C for a shorter winter heating period. The region, besides some *haveli*[1] typology housing, is largely characterise by dense settlements, and compact planning with narrow pedestrian access that serves as socio-spaces and extension of work spaces to the semi-public ground floors adjacent to the access routes. In the poorer sections of the city, houses are often constructed next to each other with little or no setbacks. Traditional homes, in the area, are introverted spaces with a courtyard open to perimeter rooms and sky, high thermal mass local stone walls of 400-500mm thick, roof with 50mm stone slabs supported by wooden beams, small size openings with *Jaalis*[3] and *Chajjas*[4] for privacy, airflow, and shade, as shown in **Figure 1**. (Archinomy. n.d.). Shops and bathroom serves as buffer, and terrace can be used for outdoor sleeping. With the first floor reserved for women folks, these traditional introverted houses have small openings on the exterior walls, but larger openings to the internal courtyard. Bidani Eco-house is located in a medium density Faridabad residential neighbourhood, mostly with 1 or 2 storey detached houses on a plot size of 1000m^2.



a) Section through private & public spaces

b) Paper model with front facing north passage

Figure 1 (a) Section of a traditional dwelling at Khampur village, near west Patel Nagar, Delhi, and (b) Model of the dwelling with cusped mughal arch entrance, small openings with *Jaalis*[3] and *Chajjas*[4]. Source: http://www.archinomy.com/case-studies/677/traditional-dwelling-in-delhi [02.06.2014].

Motivation and Objectives

The past decades have witnessed unprecedented revolution of science and technology that brought great economic and socio-cultural benefits. However, it was also a nature-human dichotomy period, when vernacularism or passive design ideologies escaped our collective wisdom, subsequent adaptation to heat producing equipments, generic modernism, and destruction of the native habitats milieu. In an emerging society where majority of its population can't afford active heating and cooling systems, passive design techniques that envisaged reduction in artificial lighting, heating or cooling, and innovative use of locally sourced low embodied energy materials are key to low-energy paradigms. In Delhi's traditional architecture, mutually shading *haveli*[1] heat sinks, high thermal mass local stone walls keep the inside cool due to time-lag in the day while its high emissivity allows rapid cooling of the surface at night. Within the framework of socio-cultural changes and new notions of lifestyle comforts, the paper aims to highlight Bidani Eco-house passive techniques, its integration with lifestyle, and subsequent low-energy paradigm when compared with GRIHA[2] energy performance benchmark.

HYPOTHESIS AND METHODOLOGY

Re-interpretation of traditional passive techniques and pragmatic response to the adverse or advantageous climatic parameters, such as: temperature, solar radiation, humidity, air speed, etc presents sustainable habitat solutions, in contemporary emerging economies. Its subsequent manifestation in architecture is primarily defined by the availability of resources on the one hand, and lifestyle-praxis on

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3. Perforated stone or lattice screens in Indo-Islamic architecture.
4. Sun-shading device for roof or windows in India, and usually supported on large carved brackets.

the other. Unlike traditional compact plans, modern buildings produced much heat of their own and heat loss or gain through appropriate ventilations or air changes through open-spaces and storage of heat or cold in high thermal mass envelopes, through responsive lifestyles, could be beneficial. Through site observations and measurements with data loggers and a series of parametric simulations and analysis with Solar Designer ver. 6, the paper highlights 1) passive low-energy architecture techniques in the house, 2) effects of ventilation modes, air change rates, and thermal mass on thermal comfort parameters in various seasons, 3) energy performance analysis with GRIHA[2] and simulations. Data loggers was logged from 7th - 10th January, 2014, in the living room and bedroom, and simulations were performed for a whole year covering 3 representative days of each of the 12 months, and best ventilation modes and air change rates were highlighted, in a manner close to how the house is operated.

THE ARCHITECTURE

Passive strategies differs base on a place climatic parameters: temperature, radiation, humidity, air speed, etc and their re-interpretation on the site, plan form and geometry, and envelope limits or allows the structures heat gain or loss. Given the composite climatic pre-requisites, Bidani Eco-house attempts to account for varied complex low-energy imperatives: minimizing summer heat gain during hot-dry season, maximization of passive ventilation during the hot-humid periods, passive solar heating in winter, and visual comforts. While the plan form and geometry's orientation aids or hinder solar radiation, the large volumetric composition of the living space with adjacent *haveli*[1] heat sink is expected to enhanced porosity, thereby, ventilation and air-changes while thermal mass walls and *mud-phaska*[5] roof attenuates heat gain in the day, it enhance heat loss at night, as shown in **Figure 3 & 4**. Additionally, mutual shading with *haveli*[1] voids and solid blocks or pergolas and trees, thermal buffer spaces, and evaporative cooling from water sprinkled on the front lawn are expected to reduce heat gain.

Table 1. Passive Design Techniques in Bidani Eco-house

Area/ Location	Passive Techniques	Functions
Site	Grass lawns and perimeter trees	Evapotranspiration, bio-purifier
Plan form & geometry	Re-interpreted *haveli*[1] typology with minimum east & west exposure	Heat sink, minimize heat gain, visual comfort, privacy
Buffer	Toilets, stores, garage on S-west	Reduce heat gain
Courtyard	Pergolas and north-east location	Shade, heat sink
Roof	RCC with *mud-phaska*[5] and stones	Insulation, thermal mass
Ceiling	Concrete, white paint	Diffused light, visual comfort
Walls	Low U-value local stones and concrete	Thermal mass, low-energy
Fenestrations	Eaves/awnings, single glass, wire mesh	Natural ventilation & safety
Floor	Stone with mortar on concrete	Ground contact, thermal mass
Verandah/ Porch	Deep eaves and pergolas	Shading

Site Landscape

The house creates its own landscape microclimate in responds to the adverse local composite climate and air pollution, within its inscribed territory. Bidani Eco-house with a built up area of 295 m² on a site area of 1000 m² has a width to depth ratio of 1:3, with the shorter side oriented towards the north and access road, which restricts design flexibility and limits generation of ideal plan form and geometry, or orientation. During the hot summer seasons, open lawns with >50% grass cover, and perimeter trees provides shade, acts as a bio-purifier to the hot-dusty air and cools the environment by evapotranspiration, and increase air speed due to narrow path of the hedges and open spaces, as shown in **Figure 2**. The site’s access road runs east west, and adjacent buildings and landscape trees provide shading from the harsh morning or afternoon sun from east and west.

Plan Form and Geometry

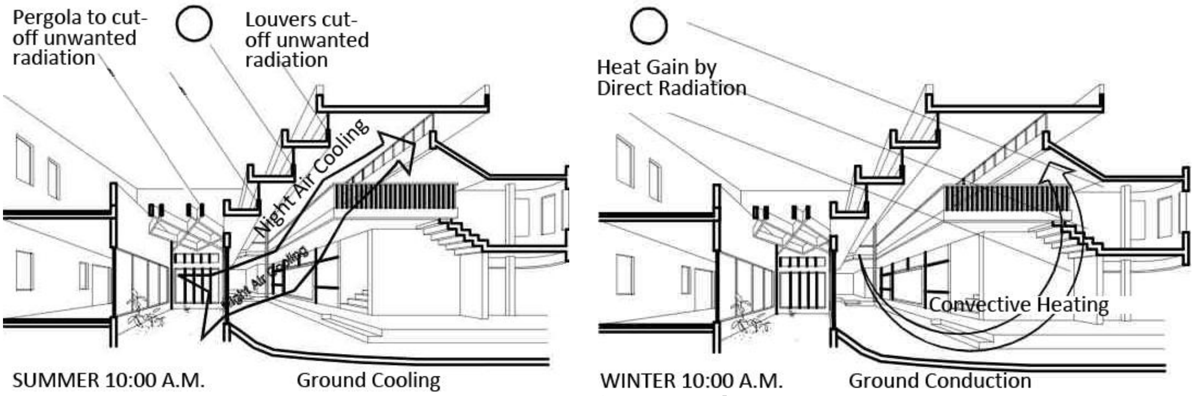
Buildings plan form's compactness or openness, and thereby, porosity to its surrounding landscape or geometric composition with respect to solar geometry, and envelope thermal mass can aid or hinder heat gain or lost, while its orientation can be crucial to control solar radiation and stabilizing extreme temperature swings. Temperature swings in the house is expected to be stabilized by shaded Northeast

5. A type of waterproofing on roof terrace in India. It consist of a mortar bed of mud soil compacted by pressing with a weighty instrument, laid to slope and tiles are laid on top.

a) Plans b) View from north entry

Figure 2 (a) Plan form with spaces layout around N-east oriented *haveli*[1], and test rooms: 1. Atrium Living room, 2. Bedroom, and (b) High thermal mass walls with local stones, or concrete and greeneries.

haveli[1] heat sinks, high thermal mass local stones or concrete envelopes to the east and west, as shown in **Figure 2 & 3**. The *haveli*[1] heat sink opened towards northeast forms the central fulcrum, like traditional dwellings, with various spaces: bed rooms, dining room, large volumetric living space, etc around it, as shown in **Figure 2(a)**. The oblique alignment of the plan form and geometry is expected to enhance passive cooling since only the narrowest elevations are exposed to the east-west low angle solar radiation while *mud-phaska*[5] roof allows the building to consistently minimize high altitude mid-day solar radiations, but allows indirect natural light for visual comforts, as shown in **Figure 3**. Pergolas, louvers, eaves, and awnings provides shades to openings. The large atrium living-room with low sill windows wraps around the shaded N-East *haveli*[1] heat sink, and the geometry of its ziggurat-like roof structure with glass and louvers on the vertical side allows for low altitude winter sun to penetrate while doubly functioning as summer time's hot air exhaust vent, as shown in **Figure 3**. These passive techniques, in combination with responsive lifestyle, such as: flexible cooling from various ventilation modes or air-changes as per seasonal conditions and evaporative cooling from vegetation are expected to maintain indoor "thermal comfort" in summer and winter, with low-energy.

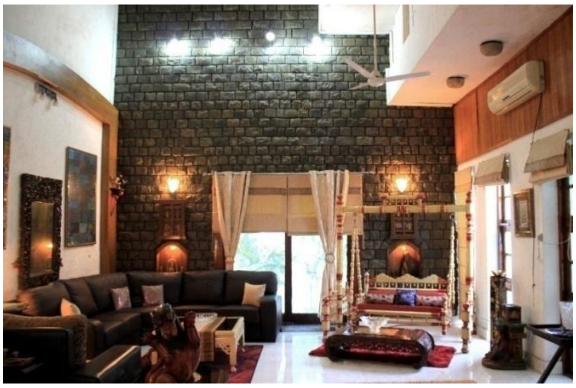


a) Summer cooling c) Winter heating

Figure 3 (a) Summer cooling with geometry & pergola shading and heat sink to *haveli*[1], and louvers, (b) Winter heating from south-east low altitude solar radiation.

Building Envelope

A building's envelope encompasses walls, floors, roof, windows, etc. The materials such as: high thermal mass local stones and concrete for the main envelope, beige granite stone floor (originally terrazzo), RCC slab roofing with *mud-phaska*[5], etc, are all locally available within reasonable distances, and thereby, low embodied energy, as shown in **Figure 4**. Local stonewalls with 1.5Wm^{-2} low U value (Roaf. S, et al. 2001) and concrete provide thermal mass to attenuate diurnal thermal swings, and single glazed windows with safety grilles and awnings allows night ventilation in summer and southeast



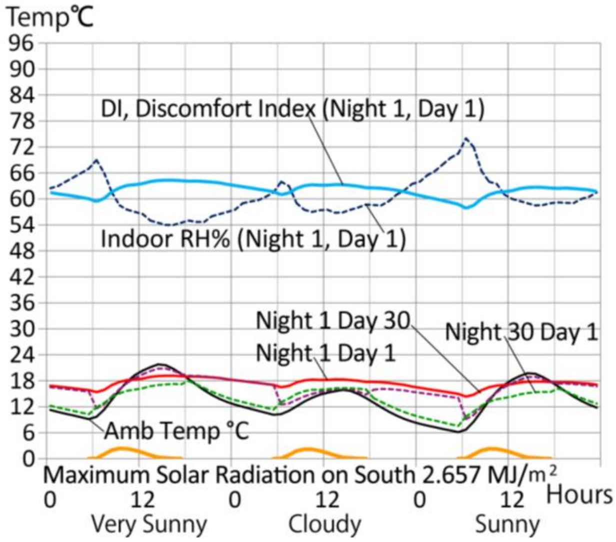
a) View of atrium living-room b) Original view of the house in stones & concrete

Figure 4 (a) Build envelope with high thermal mass local stone on east walls, and (b) North view of the original build envelop with high thermal mass stone and concrete.

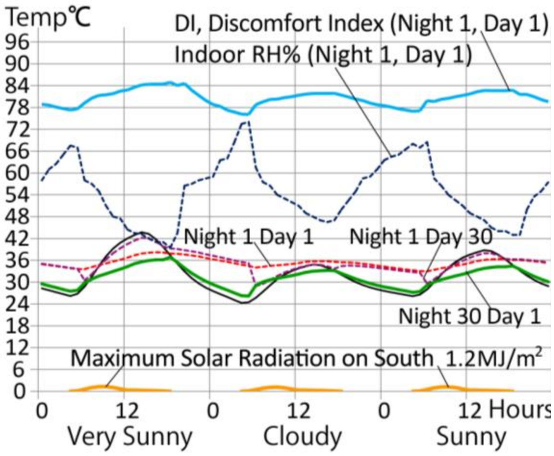
radiation ingress in winter. Buffer spaces, such as: toilets and stores, garage on the south-western perimeter, pergolas, eaves enhance thermal performance of the building by eliminating solar penetration to living spaces, and thereby, reducing cooling load in summer time, as shown in **Figure 7(b)**.

SIMULATIONS AND ANALYSIS

In order to highlight the most representative way the house is used and the role of the building fabric, in various seasons of the year, a matrix combinations of ventilation modes, and air change rates were analyze through parametric simulations with Solar Designer ver. 6 (http://qcd.co.jp/). The outcomes are discussed in hourly indoor temperature fluctuation for various climate conditions of winter and summer, and monthly best for a whole year, as shown in **Figure 5 & 6**. Representative days of each month were selected based on the weather conditions: very sunny, cloudy, and sunny. These 3 days, after extensive parametric simulations, were found to be representative of the months' ambient temperature fluctuation pattern. The simulated atrium living room is 15m x 7m x 7m high to account for extra volumes of adjacent abutting smaller rooms, and openings of size 8mX5m on the S-East and 2mX2.4m on the N-east were incorporated, as shown in **Figure 2 & 4**. N-East and S-West walls are considered to be 30cm thermal mass local stones with low U-value of 1.5Wm^{-2}, and others are 23cm concrete with plaster and no extra heating affect was considered from adjacent rooms. The floor is in earth contact, and adequate insulation added for *mud-phaska*[5] roofing along with 20cm RCC. Deep eaves, both vertical and horizontal are incorporated considering the geometry, as shown in **Figure 3 & 4**. As internal heat sources, a constant 418.68kJ/h for refrigerators, 1.8MJ/h for laundry 2 hours/day, and 1.67MJ/h for 2 family members and 2 domestic help were set everyday for 8 hrs. Windows have curtain insulations.



a) Temperature, radiation, & DI in January



b) Temperature, radiation, & DI in May

Figure 5 (a) Simulated effects of ventilation modes and air change rates in January, and (b) Simulated effects of ventilation modes and air changes rates in May, in the atrium living room.

Extensive parametric simulations for various ventilation mode and air change rates for winter (January) and summer (May), on representative days, shows the best ventilation modes: night-ventilation

(30 ACH at night, 1 ACH in the day) in summer, and in winter air-tightness (1 ACH, both in the night and day), as shown in **Figure 5**. Next, monthly best ventilation modes and ACH for a year were selected and temperature fluctuation in the test room highlighted for each month, as shown in **Figure 6**. The maximum solar radiation on the South facade was about 2.657MJ/m^2 in January and 1.2MJ/m^2 in May, and the glass serves as the media for heat egress in summer and solar heat ingress in winter, as shown in **Figure 3**. The monthly average indoor temperatures are: January, 17.4ºC; February, 19.2ºC; March, 24ºC; April, 24.24ºC; May, 31.3ºC; June, 31.3ºC; July, 30.7ºC; August, 30.4ºC; September, 28.4ºC; October, 26.22ºC; November, 22.83ºC; December, 19.06 ºC, as shown in **Figure 5 & 6**. The maximum monthly temperatures for cooling period were: May, 36.86ºC; June, 35.98ºC; July, 35.04ºC; August, 34.4ºC; Sept, 31.6ºC; October, 30.1ºC, as shown in **Figure 6**. Based on this findings and the heating, cooling and lighting loads for the year 2013, we could surmise that attenuation of indoor temperatures swings in summer and lifestyle responsive to seasonal and daily temperature fluctuations have resulted in reduce energy consumption, as shown in **Figure 7(b)**. Thermal performance of the atrium living room, "as-built orientation" and hypothetical "south orientation", was analyzed from the perspectives of energy performance, and, "as-built orientation" was about 4.9% more energy efficient under Flex Vent System, 18°C< AT <30°C, with 30ACH when AT (Ambient temperature) is 18-30°C, and 0.5ACH at other times for 8 hours occupancy per day. The envelope has sufficient number of operable doors and windows. Active cooling was required for parts of summer. However, night-ventilation allows the natural micro-climate to prevail and the room air temperature dropped to almost the same level as the outdoor temperature, while closing the openings during the day allows the high thermal mass envelope to retain lower indoor temperature throughout the day in summer, and thereby energy savings. In hot-dry periods, evaporative cooling from water sprinkled grass lawns and ventilation airflow afforded by optimized open spaces and *haveli*[1] attenuate heat gain. In winter, daytime ventilation or 'air-tightness' and green house effect from south-east facade glass could afford an average indoor temperature of about 17.4ºC and extra heating was required, as shown in **Figure 5(a)**. Discomfort Index, DI=0.81Td+0.01H(0.99Td-14.3)+46.3, where *Td*=Indoor Temperature(ºC), *H*=Relative Humidity (%), developed by the American Weather Bureau (US) in 1957, was used to calculate DI after finding the absolute humidity in g/kg of dry air, and relative humidity(%) on psychrometric chart. One percent of the population feels unpleasant if discomfort index exceeds 75, and all will become uncomfortable if it exceeds 80. The house, as-built, is uncomfortable with Discomfort Index above 75% in May, and parts of summer months, as shown in **Figure 5(b)**.

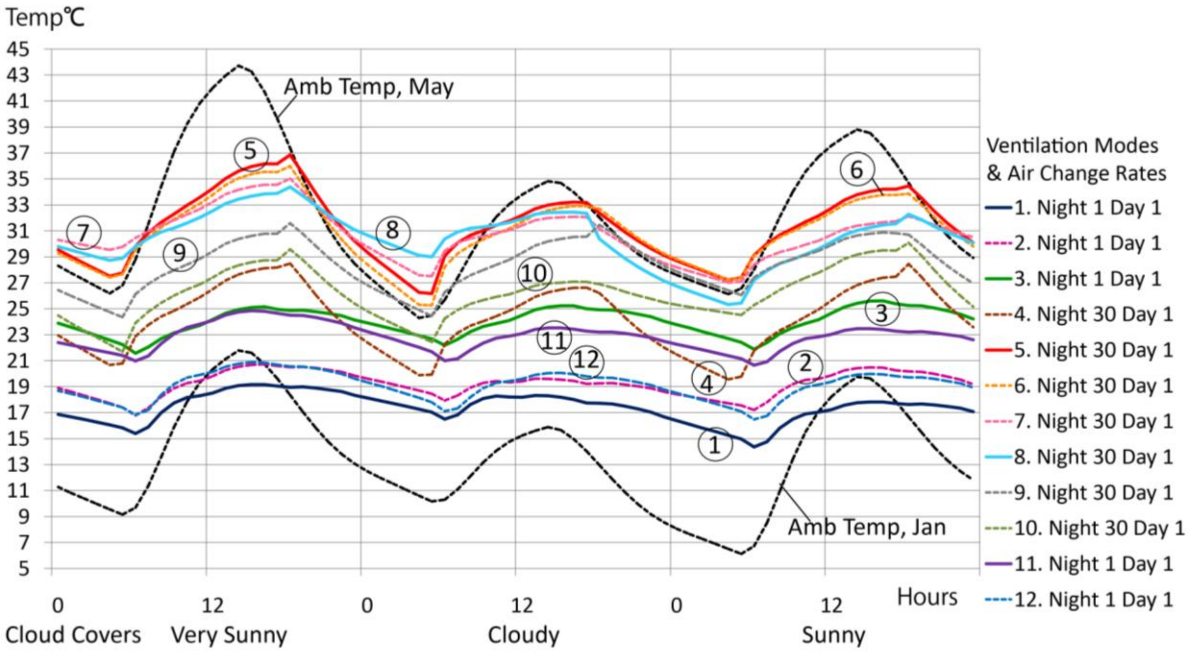
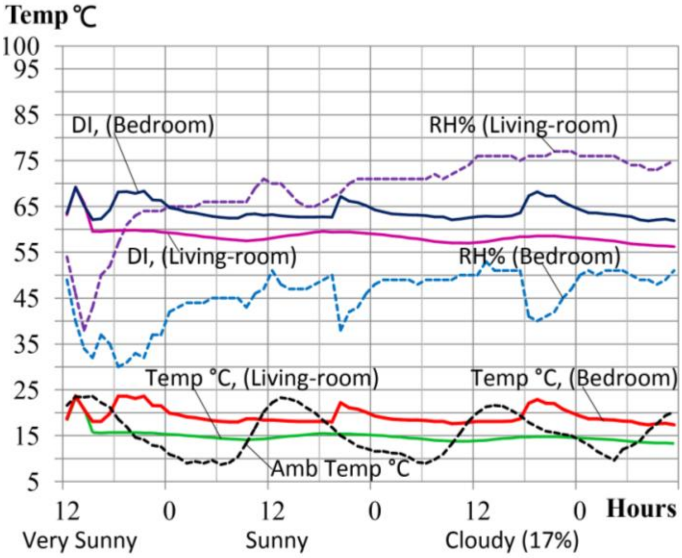


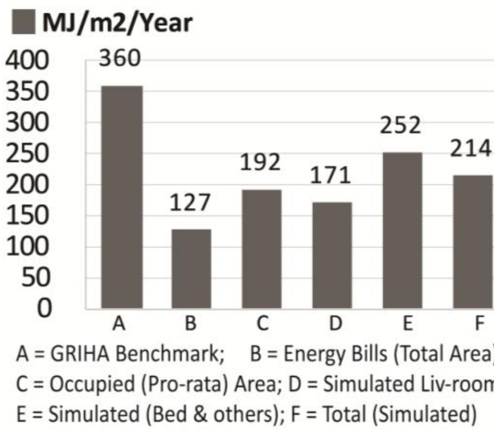
Figure 6 Simulated monthly best temperature (°C) fluctuation from January to December, in atrium living room (as-built), due to the effects of ventilation modes, air changes, shading, and thermal mass.

ENERGY PERFORMANCE ANALYSIS AND SITE MEASUREMENTS

The building envelopes high thermal mass helps in attenuating extreme temperature swings. But it also resulted in a stable low temperature, as shown in **Figure 7(a)**. The atrium living-room recorded a low temperature of 15.5ºC average, with a high of 24.1ºC because of high thermal mass and painting of the top glass openings on south-east that blocks off solar radiation. The bedroom, on the other hand, has a comfortable indoor temperature of 19.2ºC average and a high of 24.1ºC since a heater was used and the bedroom had access to Southeast and Southwest solar radiation through glass windows and thermal mass walls retains heat, as shown in **Figure 2(a)**. Through questionnaires, the authors ascertained thermal comfort, was afforded by Flex Vent system, where air-condition was on when the temperatures are not within comfort zone, say 18-30ºC. At other times, operable openings are opened and plenty of ventilation and air changes were allowed. The DI, Discomfort Index for site measurement was below 75% in both cases, as shown in **Figure 7(a)**.



a) Temperature & DI fluctuation on 7th to 10th January



b) Energy Performance Index (EPI)

Figure 7 (a) Temperature and DI (Discomfort Index) fluctuation due to lifestyle, ventilation modes, thermal mass, and shading in January, (b) Ecohouse Bidani's annual (2013) heating and cooling load and energy performance index (EPI) as per GRIHA[2] Version 3.0.

The authors conducted site measurements on the 7th to 10th of January 2014, as shown in **Figure 7(a)**. Bidani Eco-house is a residential building with a total built-up area of 295m², and a multi-generational residence. The grandparents live in the ground floor, approx. 195m^2, while the son and his wife, and grand children used to live in the upper floor, approx. 100m^2. The house occupancy is 24x7 for the grandparents, but the son and family do not continuously live in the house. Additionally, domestic helps encompassing a mother, father and 2 children also stays in the house sometimes. The possible sources of heat in the house are electronic equipments, such as: computers, TV, portable heat radiators, room electric heater, kitchen cooking stove, etc. The total heating, cooling, and lighting loads for 12 months, in 2013, was 37440MJ. According to GRIHA[2] Version 3.0, "the annual energy consumption of energy systems in a residence (24×7 occupancy) should not exceed the benchmark limits of 360MJ/m^2/year, as shown in **Figure 7(b)**. Eco-house Bidani's Design EPI (energy performance index) of 126MJ/m^2/year and 192MJ/m^2/year for the total floor area and pro-rata occupied area respectively, as per occupancy validates the performance of passive design techniques, as well as the Bidani family's lifestyle responsiveness to passive ventilation cooling or passive solar heating, as shown in **Figure 7(b)**. Simulations were done to analyze energy performance index for Eco-house Bidani, if the house was fully occupied all year round, and total heating and cooling load was 63265MJ for 295m^2. So, the simulated energy performance index (EPI) for the whole building under Flex Vent System (18-30) was 214MJ/m^2/year which is lower than GRIHA[2] benchmark of 360MJ/m^2/year, as shown in **Figure 7(b)**. Energy performance for the house was calculated by applying the actual pro-rata area of 195m2 (occupied area), to the current annual (2013) consumption of 37440MJ and the result 192MJ/ m^2/year. The actual EPI was lower than simulated heating and cooling load of 214MJ/m^2/year, which further validates lifestyle responsiveness of the occupants.

CONCLUSIONS

In contrast to the conventional practices of closing doors and windows at night for security and to keep off unwanted bugs, appropriate ventilation modes or air changes through lifestyles responsive to diurnal and seasonal climate swings, resulted in a low-energy, efficient EPI (Energy performance index) of 126MJ/m^2/year for total area. Bidani eco-house attenuated extreme climate swings of a composite climate through passive design techniques infused into the plan form, geometry, and orientation to minimize solar radiations in summer and enhance southeast winter sun or visual comfort. While local stones high thermal capacity afforded time lag, its high emissivity enhance heat loss at night. The historic usage of *haveli*[1] or the high thermal mass of local stones, and evaporative cooling prevalent to Delhi's vernacular architecture are effectively re-interpreted towards "comfort affordance" through passive cooling or heating in summer or winter. Though 100% thermal comfort is not possible through passive cooling or heating, it is possible to reduce peak energy load. The build form and envelopes contiguous relationship with climatic parameters: temperature, radiation, and airflow directly affect the internal heat gain or loss. As learning, this paper highlighted various passive cooling and heating afforded by re-interpretation of traditional passive design techniques and subsequent integration with lifestyle towards low-energy paradigms for emerging economies. In view of Delhi's extreme climate and conduction of ambient heat, good solar glass could further attenuate heat gain or loss. Furthermore, the paper validates the possibility of using an interactive design tool, Solar Designer and Energy bills or GRIHA[2] benchmark for energy performance as an effective method in assessing the design as well as lifestyle-praxis. To conclude, passive design techniques and responsive lifestyle praxis are both a necessity for low-energy sustainable habitats in emerging economies during operations.

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A Comparative Study of Design Strategies for Energy Efficiency in 6 High-Rise Buildings in Two Different Climates

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ABSTRACT

Due to the ever growing trend of urbanization and population growth, the construction of high-rise buildings is inevitable and will also continue at an ever increasing pace. However, typical high-rise buildings (the traditional template of a rectilinear, air-conditioned box) are not energy efficient in many aspects of their design. In this research the impact of architectural design elements on building energy performance will be studied through a combined literature review and case study research on 6 high-rise buildings with different degree of sustainability and located in two climate types, sub-tropical and temperate. The exterior envelope, building form and orientation, service core placement, plan layout, and special design elements like atria and sky gardens are the subject of investigation. This study found that a double-skin façade with automated blinds and operable windows besides a narrow floor plan, the correct placement of core services in regards to solar heat gains, and the application of vertical shafts like atria, which bring daylight and natural ventilation deeper into the plan, are the strategies that effectively can provide energy savings for tall buildings. However, when the building has this potential to use energy efficient design strategies, the real performance depends on how the building is used by the occupants. Designers should therefore take user behavior into account during the design stage.

INTRODUCTION

Urbanization, insecurity of resources and climate change are key challenges toward the future of cities (Dobbelsteen, 2012). As cities become denser and buildings become taller, sustainability may be at stake. Tall buildings are source-intensive due to the excessive scale and complexity of design (Cook, Browning, & Garvin, 2013). A wrong design strategy can lead to more energy consumption. This paper addresses design strategies that help a high-rise building to be more energy efficient in both a temperate and a sub-tropical climate. In order to have high performance tall buildings, first there is a need to reduce the building's demand for energy and the most straight forward approach is to design them in a way that reduces their appetite for consumption.

METHODOLOGY

6 case studies with different degree of sustainability were selected from 2 climate types (temperate & sub-tropical). For each case, building-related energy performance data was collected through a literature review and contact with the energy consultants. This energy performance data of each group of buildings in one climate (3 cases) was compared to analyze the effectiveness of different design strategies for cooling, heating, ventilation and lighting in the specific climate type. Finally, energy-efficient design solutions were defined for both climates. The selection criteria for the cases were:

- Considered by one of the rating systems or standards as a high-performance building
- Availability of building-related energy performance data (metered or simulated)
- Newly constructed office building that has been occupied for two years with at least 15 floors

The difficulty with this kind of studies is that often the energy consumption data are neither measured nor made publicly available. Therefore, it is always difficult to normalize all of the conditions between different cases. Sometimes, simulated energy data are the only source or internal conditions such as occupancy rate, building function and office equipment may vary among cases. Climate variations during different years can also influence the energy consumption. Therefore all of these conditions ideally should be accounted for when making the comparison. In this paper, the presented energy figures are delivered energy in kWh/m^2 of gross floor area, unless it is mentioned otherwise. For making the energy figures comparable, conversions were applied for some cases. The plan configurations and the energy performance data of the six cases are presented in Figure 1 & 2 respectively.

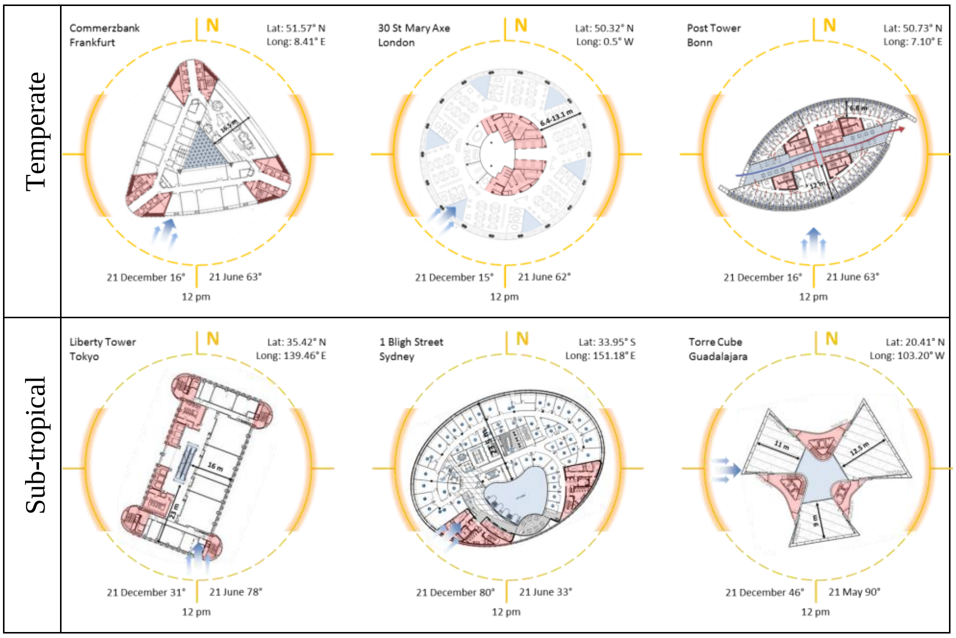


Figure 1. *Building orientation and plan configuration for the 6 buildings. Red color areas show the position of the service core and blue color areas present a vertical shaft like an atrium, a circulation void or an open void.*

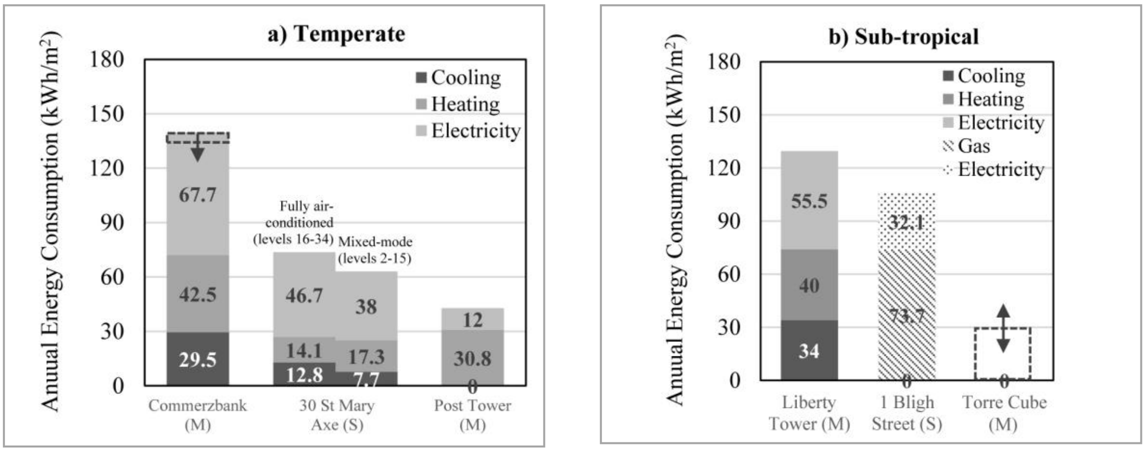


Figure 2. *Energy performance data of the six cases. (S)=Simulated; (M)=Metered; the electricity consumption is just for lighting, pumps and fans. [1]The EUI for the Commerzbank (Goncalves & Bode, 2010) and the Post Tower (S Reuss 2014, pers. comm. 19 May) were originally calculated based on the net floor area. To convert the figures from net to gross floor area an efficiency factor (net area/gross area) of 61% & 57% is considered respectively for Commerzbank and Post Tower. In addition a very small amount of the cooling load is combined with the electricity usage in Commerzbank building that should be negligible. [2]The energy consumption at 30 St Mary Axe (N Clark 2014, pers. comm. 12 May) is simulated on two scenarios: a fully air-conditioned design on levels 16-34 and a mixed-mode design on levels 2-15. [3]The energy consumption of the Liberty Tower (Kato & Chikamoto, 2002) is converted from primary energy to delivered energy with an average efficiency factor around 45.4% for power plants in Japan. [4]1 Bligh Street (Yudelson & Meyer, 2013) building use a tri-generation system for combined cooling, heating and electricity generation. The*

projected energy sources are gas and electricity. However, it is not clear how much is used to generate heat or lighting. [5]Torre Cube (Wood & Salib, 2013) does not rely on an air-conditioning system for cooling, heating or ventilation. Therefore the energy consumption is zero in this building. The electricity consumption for lighting and equipment has not been published for this building. Therefore the predicted consumption is presented with a dashed line.

TEMPERATE CLIMATE

Cooling

Among the three case studies in the temperate climate, the Post Tower has the lowest energy use (from the grid) for cooling by around zero. Cooling is provided through thermally active ceilings and a decentralized supplementary fan coil system. Cold water from the nearby Rhine River and a sunk well is used as a source. Furthermore, the building is oriented based on the sun path with the long axis almost along east-west. The Commerzbank's energy consumption for cooling is around 29.5 kWh/m^2. The building uses absorption chillers to generate cold water which is distributed through chilled ceilings. Natural ventilation throughout up to 80% of the year reduces the cooling need of this building. Both buildings have a double-skin façade with ventilated cavity and motorized blinds for solar control preventing excessive heat gains. Both buildings apply night-time ventilation and a BMS to control the operation of blinds and openings. The occupants can override this BMS to customize the climate to their desires. The Mary Axe building uses a decentralized air-conditioning system on each office floor. According to the simulation results, the cooling demand was lower when using natural ventilation in mixed mode zone compared to other one that was entirely air-conditioned. The total energy consumption of all of the 3 buildings is considerably less than of typical air-conditioned buildings.

Heating

Considering heating, the Mary Axe building has the lowest energy consumption. The air supply to the air handling units (AHUs) is provided by narrow slits between the glazing panels, then conditioned by the AHU and then distributed through adjusted ducts at ceiling level. Part of the exhaust air from the offices is used to ventilate the cavity inside the facade; therefore, in winter, the cavity will have a temperature similar to that of the indoor air, thereby reducing the heat loss through the envelope. Base on the simulation results of Mary Axe building, the heating demand is slightly higher when introducing natural ventilation into the building compared to a fully air-conditioned mode. The Post Tower can be ranked second best with an energy consumption for heating of around 30.8 kWh/m^2. The energy source is waste heat from electricity production (district heating). Furthermore, the deep cavity (120-170 cm) within the double-skin façade acts as a thermal buffer between the outdoor and indoor air. On cold winter days, fresh air firstly is warmed up in the double-skin façade before it enters the perimeter fan coil units; thus reducing the need for heating. The energy consumption for heating of the Commerzbank is 42.5 kWh/m^2, higher than of the Mary Axe and the Post Tower. The energy for heating is provided by the local district heating network and is distributed through thermostatically operated radiators. The double skin façade of this building has the narrowest cavity (20 cm) among the three buildings. However, the window-to-wall ratio of this building is lower (around 58%) than of the other cases which are fully covered with glass.

Ventilation

All of the three cases use a mixed-mode ventilation strategy (natural ventilation + mechanical ventilation). However, the duration of natural ventilation is different throughout the year. With the help of architectural elements (central atrium and the sky gardens) and special plan configuration of Commerzbank, internal-facing offices can be naturally ventilated throughout the entire year. The outward-facing offices can also utilize natural ventilation up to 80% of the year. For the Post Tower, all of the working areas and communal spaces can be naturally ventilated with a combination of cross and stack ventilation. Only interior meeting rooms and conference halls are conditioned mechanically. The outer skin of the façade is extended to create an aerodynamic form which increases the ventilation rate. In both projects, the double-skin façade is naturally ventilated and night-time ventilation is applied during summer. The office areas in the Mary Axe building are not ventilated directly through the façade. Fresh air first comes into 6 peripheral atria through small openings in the façade before this tempered air is distributed to the working stations. For the original design, it was predicted that the office areas could be naturally ventilated during 41-48% of the year. But with a change from owner occupation to multi-tenant occupation, most tenants rejected the energy-efficiency package with automated windows and choose for the year round air conditioning package instead (Wood & Salib, 2013). Because of the deep plan of this building, the central service core is mechanically ventilated. Besides, the cavity inside the facade is not ventilated with fresh air but with extracted air from the offices. Furthermore, the building does not use nigh-time ventilation.

Lighting

The Commerzbank has the highest electricity consumption (67.7 kWh/m^2) among the case studies in the temperate climate. As it is not clear how much of this energy is used for lighting, it is difficult to determine the causes for this and might be derived from a prestigious design, more office equipment, higher number of occupants per square meter or architectural design features like window-to-wall ratio and plan depth. Considering the façade transparency, the Commerzbank has the lowest window-to-wall ratio of approximately 58%. This could mean that there is more need for artificial lighting. However, a full height central atrium and 9 spiral sky gardens bring a lot of natural light deep into the building interior. In the Post Tower around 85% of the working stations are located within 5 meters from the external façade. A considerable part of the office spaces therefore utilizes daylight reducing the energy demand for artificial lighting significantly. Furthermore, most of the meeting rooms and service spaces at the heart of the building are faced toward a central atrium and can therefore also be naturally lit. The office spaces can operate in stand-by mode when the rooms are empty. From the total electricity consumption, lighting is 6.2 kWh/m^2. In the Mary Axe building, the distance between the core and perimeter ranges from 6.4 to 13.1m depending on the floor size. This building thus has a deeper plan compared to the other cases. However, the problem of a deep plan is solved here with the help of 6 triangular atria along the building perimeter. All of the rectangular office fingers can be naturally lit from three directions. The big central service core should always be artificially lit due to its central placement. The total electricity consumption for lighting are respectively 26.4 and 29.1 kWh/m^2 for mixed-mode (levels 2-15) and fully air-conditioned (levels 16-34) zones.

SUB-TROPICAL CLIMATE

Cooling

Among the cases in a sub-tropical climate, Torre Cube has the lowest energy consumption for both heating and cooling (0 kWh/m^2) because it does not depend on an air-conditioning system. Due to the mild climate in Guadalajara, buildings in this city can be naturally ventilated throughout the entire year if designed well. Solar radiation intensity, however, is very high in this area making sun-shading an essential additional strategy for passive cooling. Adjustable external screens protect this building from excessive heat gain in summer. The 1 Bligh Street building in Sydney is equipped with a hybrid tri-generation system that simultaneously generates heat, cold and electrical power. 500 m^2 of the roof of this building is covered with solar collectors that feed the absorption chiller to generate cold. Therefore, the building does not use electricity from the grid for cooling. Furthermore, the compact elliptical form has 12% less surface area than a rectilinear building of the same volume, thus reducing the heat gain/loss through the building envelope. In addition, a high-performance naturally ventilated double-skin façade with 60 cm cavity helps to reduce the heat gain through the envelope. However, there is some debate considering the land use and ecology of this building. The building's orientation and configuration of plan are mainly derived from the urban grid and the desire to maximize the view, not from environmental concerns. While the service core could have been used as solar buffer on the hot east and west side, it is placed on the south side (non-harbor side of the floor plate). The Liberty tower in Tokyo has an educational function, which because of high occupancy rates typically has a higher cooling demand than an office function. The building uses around 34 kWh/m^2 for cooling which is higher than the other two sustainable buildings. However, the 1 Bligh Street building's dependence on renewable energy (solar energy) for cooling does not mean that the cooling demand of this building is less than of Liberty Tower. This building does not seem to be oriented environmentally. The majority of lecture rooms are facing (south)east whereas the opposite (north)west contains the majority of service areas. Vertical and horizontal concrete fins on the façade protect the openings from high solar gains in summer.

Heating

As mentioned before, Torre Cube has zero energy use for heating due to the mild weather conditions of Guadalajara. During the cold months (December and January) daily mean temperature is around 17°C. As a result, the internal and passive solar heat gains are sufficient to warm up the small interior office spaces. Liberty Tower's heating load is around 40 kWh/m^2. The rectilinear shape of the building increases the surface area and therefore the heat gains/losses through the envelope. 1 Bligh Street building uses 73.7 kWh/m^2 gas to feed a gas-fired tri-generation system which generates electricity and useful heat. It is up to 50% more efficient compared to conventional grid-connected systems. From the waste heat, 'free' cooling and hot water can be generated. The office spaces are fully air-conditioned and separated from the atrium by glass walls. Extracted conditioned air from the offices is used to temper the naturally ventilated atrium. However building's energy use for heating has not been published.

Ventilation

1 Bligh Street has two strategies for ventilation. The communal heart of the building is naturally ventilated but the working areas are fully mechanically ventilated. Natural fresh air is provided through an opening on the ground floor and a sky garden on the 15th floor and is distributed on all floors by stack ventilation in a full height atrium. The building is designed in a way that the perimeter cellular offices may potentially use single-sided natural ventilation if the interior glass panels are replaced with operable ones. But the deep floor plate does not allow for cross ventilation. With the help of natural ventilation, the annual cooling demand at Liberty tower was reduced by 17%. Two architectural elements that effectively have improved this natural ventilation strategy are the escalator void and a wind floor on the 18th floor on top of the circulation shaft. CFD analysis has shown that the wind floor increases the air flow rate by 30% (Kato & Chikamoto, 2002). As the escalator void is not segmented, there is a risk of extreme stack effect and draft inside the building. Furthermore, the introduction of fresh air directly into the working areas might provide discomfort especially for the occupants sitting near the air inlets. In the Liberty Tower cool fresh air comes in directly through the inlets below the fixed windows. The inability of the occupants to control their operation (fully controlled by a BMS) may limit their comfort and may result in user dissatisfaction (cold feet). The Torre Cube building uses different architectural elements to provide both cross and stack ventilation. Fan-shaped office wings help to funnel the air across the working spaces before it is exhausted through a central open void. Three open spiral sky gardens lead to a higher air circulation in the void. However, without a CFD analysis it is not clear if the sky gardens have a positive or a negative effect on buoyancy in the central void.

Lighting

1 Bligh Street has a fully transparent façade. However, in 1 Bligh Street just 30% of permanent working stations are within 5 meters of this façade. Due to this deep plan (23.5 m from façade to central void), there are three working zones between the building perimeter and the atrium. A central atrium and transparent partitions are used to increase natural light penetration. Temporarily used spaces such as meeting rooms are placed in the mid-zone. The figures of electricity consumption for lighting, fans and ventilation has not been simulated but the total delivered electricity is around 32.1 kWh/m^2. Torre Cube's

electricity use for lighting has not been published. Because of a central void, the office wings in this building receive daylight from two sides, which allows for a deep office plan of about 9-12.5m. The electricity use for lighting and pumps of Liberty Tower is around 55.5 kWh/m^2. Considering the façade transparency, the Liberty Tower and Torre Cube have compared lower window-to-wall ratio than 1 Bligh Street.

EFFECTIVE DESIGN STRATEGIES FOR HIGH-RISES

General design strategies for high-rise office buildings

Concerning plan configuration, it is important to place the permanent work stations close to the envelope to reduce the need for artificial lighting. Dividing the internal zone into areas with different temperature is another important strategy that can reduce the cooling/heating load of high-rise buildings. Office workers expect a high degree of comfort in their work stations but tolerate a little bit of discomfort in lift lobbies and communal spaces.

Plan form and building shape (or compactness) can influence the amount of heat gain/loss through the envelope. Circular and elliptical forms have an exposed surface area that is respectively 25% and 12% less than of a rectilinear building of the same volume. Furthermore, an aerodynamically curved form minimizes wind turbulence and downdraft at street level.

Furthermore, the effectiveness of natural ventilation and daylight depends strongly on how the openings and solar shading devices are controlled. The absence of a central BMS might cause problems in attaining the right adjustments for providing indoor comfort conditions and may increase the energy consumption. Smart occupancy sensors cut down unnecessary consumption for lighting, and mechanical ventilation. In cellular offices, it is important that occupants can override the BMS to ensure their individual comfort. Psychologically, occupants with more control over their environment are more tolerant to high or low temperatures. However, the BMS should automatically switch off the air-conditioning system if occupants decide to open the window.

Design strategies for high-rise office buildings in a temperate climate

Façade transparency and plan depth are the two dominant factors with great influence on the electricity demand for lighting. A fully transparent façade is a common strategy in a temperate climate. However, it is important to provide a balance between the use of daylight, the solar heat gain in summer and the heat loss in winter. A double-skin façade with a deep cavity is an effective strategy for reducing the cooling and heating loads of high-rise buildings in temperate climates. A double-skin façade can act as a thermal buffer between the outdoor and indoor environment. Moreover, offices next to this façade can use natural ventilation for a longer period of time if fresh air first passes through the cavity in the double-skin façade before entering the offices. However, an effective ventilation strategy is highly needed inside this cavity especially during summer, otherwise the double-skin façade would act like a greenhouse and transfer a lot of heat into the building. Solar control devices within the cavity such as a motorized venetian blind allow for passive heating in winter, but prevent unpleasant glare and overheating in summer.

A mixed-mode (natural and mechanical) ventilation strategy can reduce effectively the energy demand for cooling and mechanical ventilation. Some architectural elements that can help the air intake, circulation and exhaust are sky gardens and vertical shafts like atria and circulation voids. When using a full-height atrium, there is a risk of high temperature differences and extreme stack effects and drafts. For controlling this excessive stack effect, a full-height atrium is usually segmented into smaller zones with lower pressure difference.

Design strategies for high-rise office buildings in a sub-tropical climate

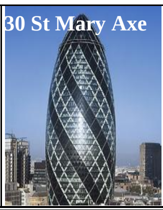
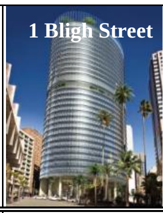
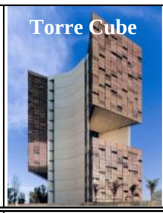
In a sub-tropical climate, solar radiation intensity is high. Therefore the most effective design strategies are those that reduce the solar heat gain. Such strategies include limited façade transparency on the east and west side of the building, the placement of service cores on the hot sides (double-sided core on east and west) and the extensive use of shading devices. Glazing type is usually double-glazing with low-e coating. Due to high solar radiation angle in these areas, it is also important to shade the roof surface and utilize energy generation systems like solar collectors or PV panels.

Placing the work stations along the north and south façade is a good strategy for reducing the electricity demand for artificial lighting. However, the size and position of openings should protect the occupants form direct solar radiation and glare. Using external shading and indoor blinds improves the quality of daylighting. As in a temperate climate, natural ventilation is also an effective solution for reducing the cooling demand in a sub-tropical climate. However, introducing humid outdoor air may reduce thermal comfort of the occupants as a result of which constant humidity control is an essential element of such a strategy.

CONCLUSION

Design strategies for tall office buildings were investigated through a comparative study of 6 high-rises in a temperate and a sub-tropical climate. The total energy consumption of all of the 6 selected cases are considerably less than of typical air-conditioned buildings. This research explained the most effective design strategies that sustainable high-rises using them to reduce the energy consumption for cooling, heating, ventilation and lighting in both climates as the summery is presented in Table 1. It is found that a double-skin façade with automated blinds and operable windows besides a narrow floor plan, the correct placement of core services in regards to solar heat gains, and the application of vertical shafts like atria, which bring daylight and natural ventilation deeper into the plan, are the strategies that effectively can provide energy savings for tall buildings.

Table 1. Comparison of the design strategies and the energy performance for the six cases.

	Temperate			Sub-tropical		
Design strategies						
Double-skin facade	+	+	+	NA	+	NA
Deep cavity	-	+	+	NA	+	NA
Ventilated cavity	+	+	+	NA	+	NA
Natural ventilation	+	+	+	+	+	+
Nigh-time ventilation	+	-	+	+	-	-
Shading devices	+	+	+	+	+	+
Narrow plan	+	-	-	-	-	+
Energy recovery	+	+	+	+	+	NA
Energy absorption	-	-	+	-	+	-
Environmental orientation	+	+	+	-	-	+
Greenery systems	+	-	-	-	-	-
Annual EUI (kWh/m^2 gross floor area)	139.7 (kWh/m^2)	63 - 73.6 (kWh/m^2)	42.8 (kWh/m^2)	129.5 (kWh/m^2)	105.8 (kWh/m^2)	-0- Excluding electricity

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The Potential for Natural Ventilation as a viable Passive Cooling Strategy in Hot Developing Countries

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The Potential for Natural Ventilation as a viable Passive Cooling Strategy in Hot Developing Countries

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ABSTR ACT

Natural ventilation offers opportunities for reducing cooling energy-demand at low-cost in developing countries with limited resources. In this paper the natural day- and night-time ventilation potential for cooling in hot-arid and hot-humid Mediterranean climates is characterised against the key weather and building parameters affecting its performance. In particular, the study seeks to quantify the limits of outdoor environmental conditions under which natural ventilation is an effective strategy for achieving thermal comfort. Furthermore, the study explores the effects of certain building characteristics that enhance the performance of natural ventilation such as ventilation rates and thermal mass. This is achieved by short-term environmental monitoring and dynamic energy modelling of selected naturally ventilated domestic buildings in Lebanon and Jordan. The summer monitoring regime compared external and internal temperatures, relative humidity and air velocity in free-running 'well-designed' buildings in order to identify the external environmental limits for effective day- and night-time ventilation. Computer modelling of the monitored buildings was undertaken using IES VE to determine the design parameters affecting the performance of natural ventilation. Initial results show that computer modeling overestimate ventilation rates through windows with Venetian shutters.

INTRODUCTION

Natural ventilation is considered one of the simplest passive cooling strategies that allow the provision of a comfortable indoor environment at low operating costs. The two most beneficial natural ventilation regimes were considered:

• Day time ventilation DTV (direct cooling); when buildings are ventilated during the day, and internal temperature and humidity are expected to follow closely external environmental conditions. DTV can enhance occupant comfort through higher indoor air velocities so DTV should only be applied when outdoor temperatures are within comfort limits and acceptable indoor air speed may be achieved, (Givoni, 1998).

• Night time ventilation NTV (indirect cooling); where buildings are ventilated only at night can reduce the peak internal temperatures from external levels by pre-cooling the interior exposed thermal mass of a building.

Many studies have been conducted to examine the potential of natural ventilation and the effect of different parameters on its performance. De Graca, Chen, Glicksman and Norford (2001), investigated DTV and NTV for an apartment building in Beijing and Shanghai. Shaviv, Yrzioro and Capeluto (2001), assessed the potential of NTV in terms of the reduction in maximum internal temperature as a function

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of the diurnal temperature swing. They concluded that in hot-humid Mediterranean climates a reduction of 3-6° C could be achieved by NTV depending on the level of thermal mass, air change rate and diurnal temperature swing. Artmann, Manz and Heiselberg (2008), conducted a parameter study on the performance of NTV for different moderate climates, building constructions, heat gains, air flow rates and heat transfer coefficients. The study found that even with moderate air change rates, overheating degree hours were considerably reduced by NTV. Yao, Li, Steemers and Short (2009) summarised current research on the potential of natural ventilation in two categories, the first focused on the calculation of ventilation driving forces (wind or stack effect) and the second on calculation of internal air temperature using computer thermal simulation or CFD programs.

All the above studies used dynamic computer modelling tools in their assessment of natural ventilation. The vast majority of recent research on real naturally ventilated buildings was conducted to assess air quality or thermal comfort expectations and boundaries and were mostly related to studies on the adaptive thermal comfort theory. Fewer studies report on actual monitored cooling performance of naturally ventilated buildings. Examples of such studies are, Kolokotroni, Webb and Hayes (1998) on the applicability of NTV as a summer cooling strategy for office buildings by taking field temperature measurements. The results found that internal temperature was up to 4°C lower than the external temperature at the start of the following working day; however, due to internal gains the internal temperature had risen again by midday. Givoni (1998) examined fan assisted night ventilation for both shaded and unshaded windows in San Diego with three different levels of thermal mass levels, (light, medium and heavyweight). The study found that higher thermal mass lowered the maximum internal temperatures by 2°C and that they remained lower than external air temperatures throughout the day. However, buildings with low thermal mass failed to reduce internal temperatures below outside conditions and in some cases interior temperatures were higher. Based on this and several other studies on natural ventilation Givoni developed building bioclimatic charts BBCC with recommended boundaries for the external environmental conditions under which natural ventilation would be an effective strategy.

It is well established that there are also key supporting factors for successful natural ventilation, namely adequate shading to limit unwanted excess solar heat gains, limiting internal heat gains from appliances, appropriate thermal mass and insulation. However, there is a lack of post-occupancy performance data from naturally ventilated buildings in hot climates where such strategies were applied. Most post-occupancy studies focus on the energy consumption of buildings rather than their passive performance. Computer simulation tools are widely used to predict the performance of natural ventilation without validation through real building monitoring. This paper reports on the monitoring of two naturally ventilated, best practice, new domestic buildings. Short-term environmental performance monitoring was conducted to establish the true natural ventilation potential of ‘well-designed’ buildings. The monitoring results were compared with the natural ventilation potential suggested by Givoni’s BBCC, and then the performance predicted by Dynamic building simulation tool IES.

METHODS:

The selected buildings:

1. Aqabba house AREE: a three story house, with a total floor area is 235 m2. The house was designed to be a prototype for low energy houses in the Aqabba region in hot-arid climates of Southern Jordan; it has 45 cm thick cavity walls of concrete blocks.
2. Casa Batroun: First and only BREEAM excellent awarded house in in the hot-humid climate of the eastern Mediterranean region of Lebanon, The house is separated into a ground floor flat and a 1st floor flat with two different constructions, masonry and timber, respectively.

Both buildings were well shaded and had external Venetian shutters installed on the majority of windows, figure1. The monitored buildings were also unoccupied for the majority of the time except for night; however, kitchen appliances such as fridge and freezer remained on during the monitoring period and thus contibuting to internal gains.

The monitoring methodology:

Given that both buildings were classified as heavy weight, the potential benefits of thermal mass combined with day-time cross ventilation and night-time cross ventilation were examined. In order to measure the outdoor microclimate the following external environmental parameters were monitored: i) air temperature, ii) relative humidity, iii) wind speed and direction, and, iv) solar radiation on the horizontal plane. The internal measurements monitored were; relative humidity, air temperature and air velocity. Wireless sensors were placed on tripods at a height of 1.2m, (the normal seated height of occupants) in the middle of the rooms and transmitted to a data logger. The parameters were sampled at one minute intervals with averages recorded every 30 minutes. The monitoring period lasted for 10 to 14 days in each building depending on accessibility to the buildings, allowing 5 to 7 days for each of the two ventilation strategies. In DTV mode, windows were opened from 7am to 8pm and in NTV mode, from 10pm in AREE, and 8pm in Casa Batroun until 7am the following day. In order to establish the effectiveness of the two strategies the following performance indicators were examined; reduction in peak internal temperatures, and reduction in Kelvin hours (KhR) between external and internal temperatures over the period of ventilation, calculated in Kelvin hours (Kh).

Figure 1 AREE (left), Casa Batroun (right).

Computer modelling of the monitored buildings:

Both monitored buildings were modelled for DTV and NTV performances using dynamic computer simulation. There are several programs and detailed thermal simulation tools able to model the energy performance of buildings. Computer software Virtual Environment IES was used to undertake the simulation as it not only is the approved energy software in the United Kingdom for energy analysis and Part L regulations (IES VE, 2010), but is also extensively used internationally (Altamimi & Fadzil, 2011; Rajagoplan & Luther, 2013; Blight & Coley 2013). The program comprises an integrated suite of applications, only four of which were used in this modelling work; ModelIT for the basic building geometry, SunCast for shading analysis, ApacheSim for thermal simulation, and Macroflo for building ventilation.

A performance gap is frequently reported in literature between predicted and monitored energy use in buildings. Although the focus of this paper is on natural ventilation and not energy use, the following observations are still valid. One of the main reasons for the discrepancy between predicted and actual building energy performance is due to poor assumptions regarding occupants' behaviour/patterns or issues with the built quality, (Menezes, Cripps, Douchlaghem & Buswell 2012). Other reasons include unreliability of weather files used, with various studies showing that using different weather files resulted in different simulation outputs. However, it is generally agreed that TMY2 weather file gave the closest output match to measured consumption (Crawley 1998; Michopoulos, Voulgari, Papakostas & Kyriakis 2012). To limit such possible discrepancies the following measures were taken:

- Weather files used in the simulation were edited using a software 'epw creator'. The new files corresponded to onsite measured weather variables; DBT, RH, Wind speed and direction and Global solar radiation. Diffused and direct normal radiation were calculated from the measured data and included in the new weather files.

- Occupancy profiles: Both monitored buildings were unoccupied for the majority of time, at durations were there was limited occupancy, detailed use of the building was recorded and reflected in the model.
- Information on the buildings' material specifications and constructions were provided by the architect and consultants (Karkoor, Visser 2013). However, issues with poor build quality and inaccuracies in the specifications of locally produced materials may still exist.

RESULTS:

DTV & NTV monitoring of AREE:

Main observations, figure 2:

1) Up to 7K reduction in maximum temperature from external maxima with DTV and up to 9K with NTV. The lowest recorded temperatures were on the ground floor in the north-east room L0R3. The highest recorded internal temperatures were in room L1R4 on the 1st floor corridor, which had a south-west-west facing window and higher glazing ratio than other rooms. Additionally, this room had an external overhang while most other rooms had Venetian shutters.

2) Using NTV the day time internal temperature increased by only 2K compared to night time levels.

To quantify and compare the overall performance, the Reductions in Kelvin degree hours (KhR) between internal and external temperatures were calculated and are shown in figure 3. Higher values of Kelvin degree hours indicate better ventilation/cooling performance.

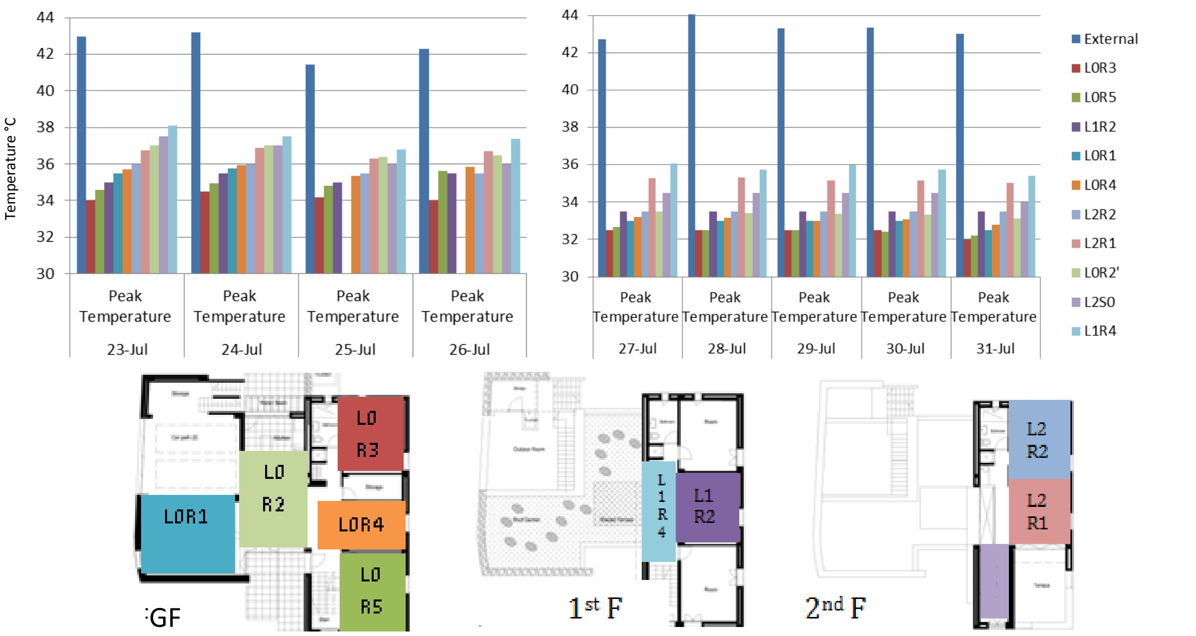

Figure 2 a) Internal peak temperatures for DTV (left), b) for NTV (right) at AREE.

It is apparent from figures 2 & 3 that NTV has a better cooling potential than DTV for the hot arid climate of Aqabba, because of lower peak temperatures and more extended periods of reduction from outdoor temperatures. However, even with NTV internal temperatures remained above 30°C at all times during the monitoring period in peak summer.

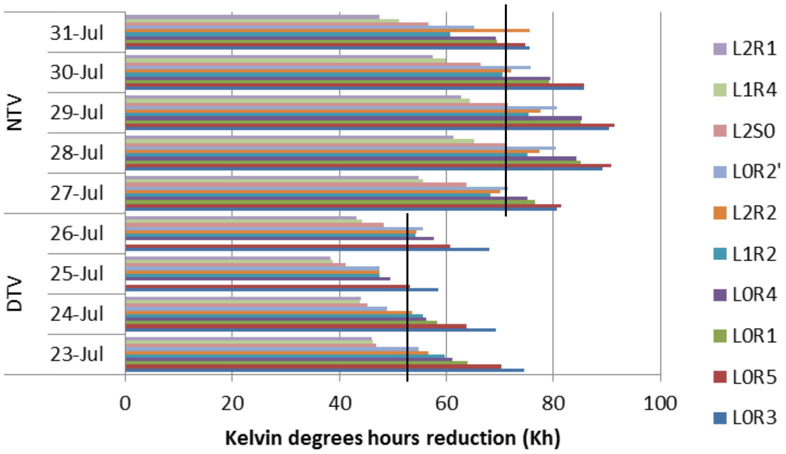

Figure 3 Kelvin degree hour reduction from external temperature levels, DTV, NTV average KhR=53.2Kh, 72Kh respectively, a 36.8% increase from DTV.

DTV & NTV monitoring of Casa Batroun:

Similar observations to AREE were made in terms of the reduction in internal temperature. However, more interestingly the performance of the two different floors differed significantly. Temperatures in the top flat were higher than the ground floor flat, (shown in figure 4), because; a) the ground floor was better shaded by nearby trees and adjacent buildings, b) the 1st floor had a higher exposed surface area resulting in additional solar gains through the roof, and walls, c) the effect of the ground floor's higher thermal mass in storing coolth was more noticeable with NTV, where day time internal temperatures remained only 2K higher than night time levels. As for KhR an average KhR=44.5Kh, 61Kh for DTV and NTV, respectively, which is a 37% increase for NTV from DTV.

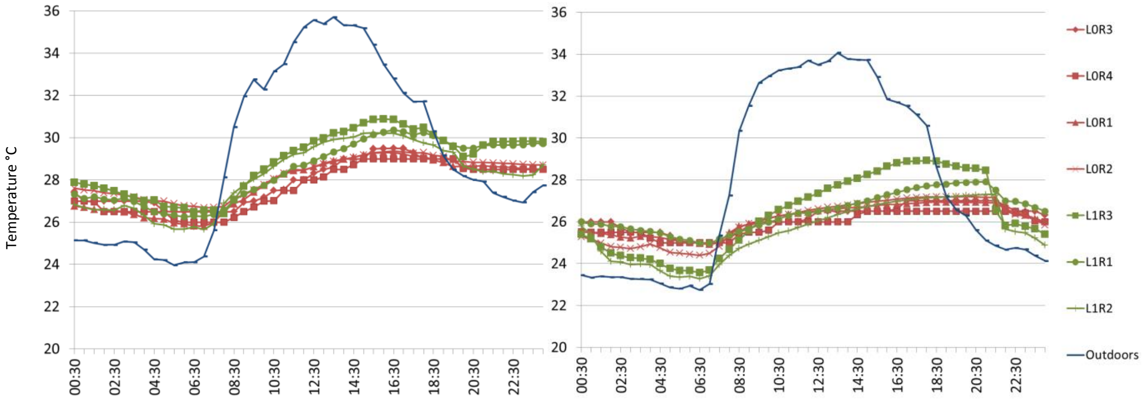

Figure 4 Internal temperatures in the Ground floor (masonry construction) in red, 1st floor (timber construction) in green at Casa Batroun, a) DTV (right), b) NTV (left).

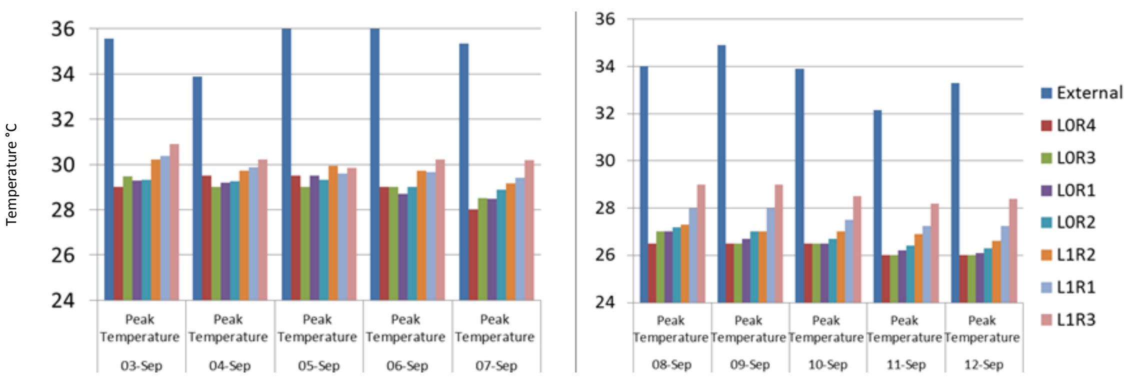

Figure 5 a) internal peak temperatures for DTV (left); b) for NTV (right) at Casa Batroun.

The monitored data of both buildings indicated that, the internal relative humidity followed external RH very closely. Recorded airspeed in the middle of the rooms that had Venetian shutters was minimal, while a maximum of 0.4m/s was recorded in a room that had an open terrace door with no shutters. Such low air velocities mean that relying on naturally driven air movement to provide cooling sensation for occupants is not possible.

Building Bioclimatic charts BBCC:

BBCC offer an easy method for initial assessment of the potential of a passive design strategy at early design stages. It suggests a comfort zone and the boundaries of climatic conditions within which DTV and NTV and other passive strategies can provide comfort. The boundaries are plotted on a conventional psychrometric chart. The best-known BBCCs are those developed by Givoni (lomas, Fiala, Cook & Cropper 2004). In this study, although internal temperatures remained above comfort levels for the majority of the time, the enhancement of internal conditions when adopting DTV strategy is much higher than that expected in conventional buildings, or of that suggested in Givoni’s BBCC; where it was limited to only 2K reduction. One possible explanation for this discrepancy between the findings of Givoni and those observed in this study, is that Givoni based his work on the monitoring of ‘thermally heavy’ buildings which had only 10cm thick concrete walls with insulation (Givoni, 1988), while AREE and Casa Batroun had about 45cm thick walls. On the other hand, for NTV the BBCC suggests up to 8K extension of the comfort zone which is consistent with the results reported in this paper. Therefore, based on the initial results of this study, high mass, well insulated and well shaded buildings, with limited internal heat gains would exhibit boundaries for DTV and NTV as shown in figure 6.

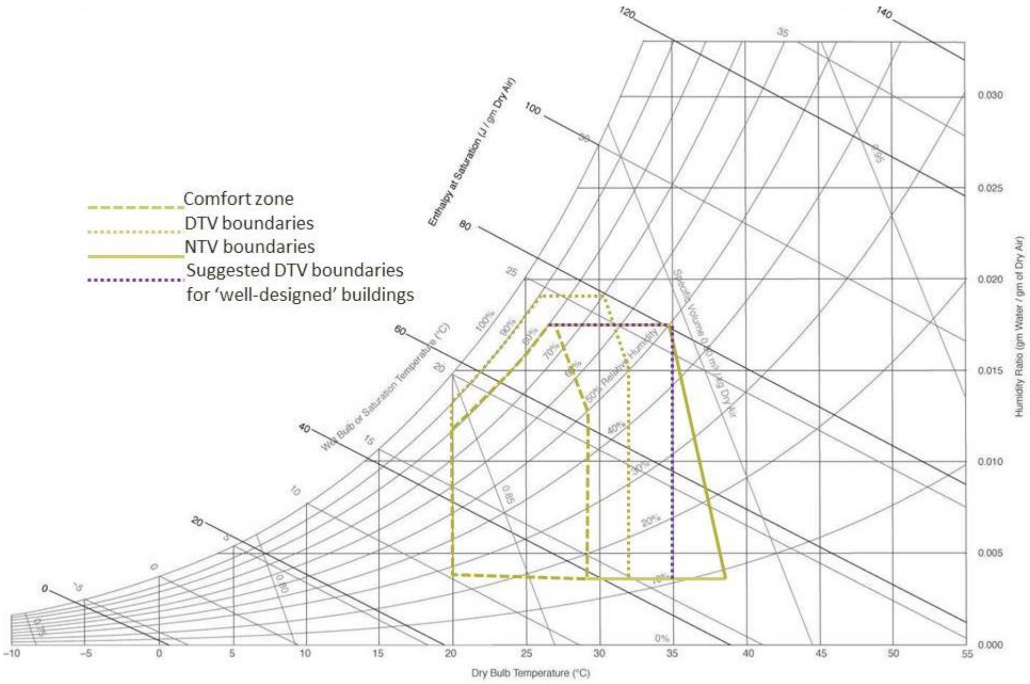

Figure 6 Givoni’s BBCC for developing countries with new suggested boundaries for DTV.

IES modeling results:

The initial analysis of DTV performance has resulted in the model over predicting the rise in internal temperature in both models (figure 7a). In other words, the buildings performed better in reality than predicted by the simulation software. Similarly in NTV analysis (figure 7b), predicted temperatures dropped down below measured values during ventilation periods and increased above monitored levels during day-time. Clearly there was a discrepancy between measured and modelled results and the building seemed to perform better than predicted through simulation. The following sensitivity analysis was undertaken to identify the reasons behind such a gap.

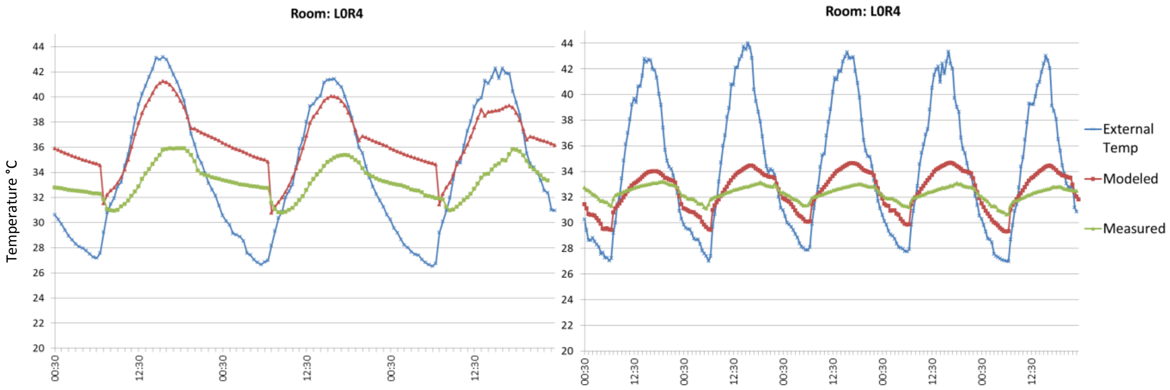

Figure 7 comparison between modelled and monitored results for one room in AREE, a) DTV (left), b) NTV (right).

Sensitivity analysis:

1. Thermal mass: a range of thermal capacities were modelled, by increasing either the specific heat capacity of materials or their density, each material specification was increased to its highest realistic value as given in CIBSE guide A. Although such increases resulted in aligning the monitored and modelled temperatures closer when windows were closed, it had no significant impact when windows were opened. During ventilation hours, the model behaved in a similar way to the base case model. This indicated that the main issue could be in higher predicted ventilation rates.
2. Ventilation rates: most windows in both buildings had louvered Venetian shutters installed in addition to bug meshes, which will have an impact on the airflow rate through these windows. Macroflo allows the user to choose a window type for each window; louvered windows were chosen for windows with Venetian shutters. Data inputs required were the openable area and the discharge coefficient C_D. A discharge coefficient relates the volume flow rate through an orifice to its area and the applied pressure difference (Karave, Stathopoulos & Athientis 2007). Several parameters affect the C_D; these parameters are the opening area, wind speed, wind incident angle, and location of the opening in the façade (Karava, Stathopoulos & Athientis 2004). Due to the difficulty in determining the C_D without testing, a range of discharge coefficients were considered. The discharge coefficient for a sharp edged orifice such as a window is usually taken as approximately 0.6 to 0.65 (ASHRAE fundamentals 2009), manufacturers' data showed that louvered ventilators C_D ranged from 0.3 to 0.1 (Renson 2009; Architectural louvers 2007). Therefore, a series of simulations with different C_D was conducted. 5 cases were studied with C_D equaling 0.4, 0.3, 0.2, 0.1 and 0.05. For every 0.1 reduction in C_D, a reduction of approximately 25% was achieved in air change rates ach for the house. However, not even the lowest ventilation rates achieved (8 to 20ach, for C_D = 0.05) brought the predicted internal temperatures significantly closer to the measured ones, figure 8 (a). Going below C_D = 0.05 is realistically not possible as it results in an effective orifice area < 3% of window area. Figure 9 (a) shows the airflow in L0R5 for different C_D, (b) shows airflow in different rooms for C_D = 0.3.

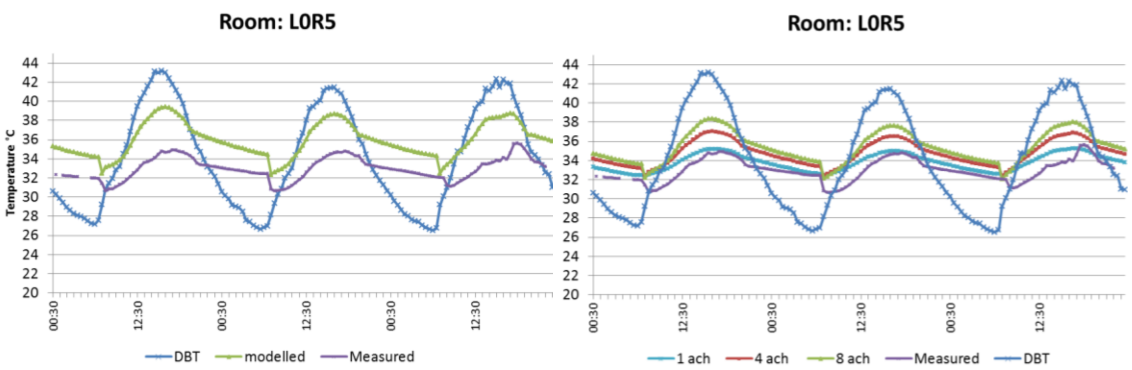

Figure 8 AREE DTV measured and modelled internal temperatures, a (left), b (right).

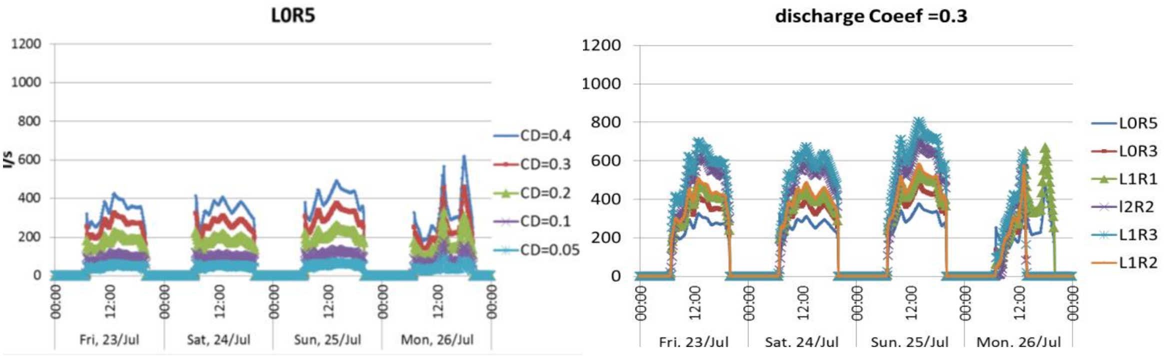

Figure 9 AREE DTV a) airflows l/s in L0R5 (left), b) air flows l/s for C_D = 0.3 (right).

IES provides an option where Macroflo can be turned off and ventilation introduced through ApacheSim as natural or auxiliary ventilation. In order to determine the ventilation rate that would bring predicted temperatures down to the monitored levels; natural ventilation was introduced starting from 1ach to 10ach in addition to a continuous infiltration rate equal to 1ach. As could be seen in figure 8b, higher ventilation rates resulted in higher internal temperatures and the best match to monitored internal temperatures was achieved for 1ach. Additionally, low ventilation rates resulted in a mismatch in some observed ventilation patterns, such as the drop in internal temperature early in the morning when windows are first opened, as seen in Figure 8b.

DISCUSSION:

It was not possible to determine the actual ventilation rates in the monitored buildings as no such measurements were taken onsite. However, the recorded airspeeds in the middle of rooms indicated that there was a considerable air movement in some rooms which had no Venetian shutters, yet internal temperatures were much lower than predicted by the model. The model only achieved similar internal temperatures to the measured ones when there was very little to no ventilation. This indicates that whenever the modelled building is ventilated, internal temperatures closely follow external DBT regardless of the levels of thermal mass or ventilation rates. Additionally, it is clear from the sensitivity analysis that there is an issue in representing open windows in computer dynamic simulation tools such as IES because very high ventilation rates were predicted even for very small C_D. A study by Coley (2008) on top hung window performance in IES found that the ventilation rate depends, to a great extent, on how the windows are represented, whether as a vertical 'arrow slit' hole in the wall or as a horizontal 'letter box' opening. False representation can result in up to four times higher airflows. Although IES provides an option for windows with louvers, their representation is not clear. Other parameters may be causing this performance gap and require further detailed investigation.

CONCLUSIONS:

The study presented investigated the free-running performance of two well-designed buildings in hot climates. The study found that up to 6K reduction could be expected for DTV and 9K for NTV. These findings were compared to previous studies and plotted on BBCC. Using computer modelling tools is a widely used approach for evaluating the performance of natural ventilation. Therefore, the monitored buildings were then modelled using computer software IES VE, in order to validate such an approach. The initial modelling of both buildings predicted higher internal temperatures than experienced in reality. A sensitivity analysis for AREE was conducted, thermal mass and ventilation rates were analysed. It was found that a ventilation rate of 1ach gave the closest match to monitored values. Low air-change rates however, were not possible to achieve in IES through opening windows in Macroflo, but rather it should be introduced in the thermal model ApacheSim as a fixed natural ventilation rate. Further investigation is required in order to fully understand how best to represent complex windows geometries in computer models, as this variable has a great impact on ventilation rates and consequently the internal temperatures. Further research is needed to identify other key factors responsible for the performance gap.

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Shop Window Lighting: the Use of Sun to Improve Visual Appeal and Reduce Energy Demand

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ABSTRACT

The present study deals with the potential reduction of energy consumption for the lighting of shop window displays. Urban commerce has a very high impact on economics and at the same time, it is a highly energy-consuming sector. Light has the power of attracting people´s attention, which is one of the goals of the trading and selling activity and very high illuminance levels are usually recommended. In the Mediterranean areas, where daytime lasts for many hours, commercial activity takes place mainly under sunshine conditions and shop windows frequently fail to fulfil their main corporative goal, namely the unobstructed observation of the products exhibited. The necessary increase of artificial lighting illuminance levels to accent interior light conditions, due to extremely high-luminance urban surroundings, leads to an important increase of energy consumption, as a common solution. Nevertheless, the results are generally very poor, because reflections and other kinds of visual problems still defy solution and the final result is an economic and energy waste during daytime, especially in low latitude countries. The present study evaluates the visual and energetic benefits of an innovative passive design that obstructs solar rays and redirects them into the interior of the shop window scene. A scale model of this new design confirms the visual benefits produced by its use, via the different luminance maps tested. This new lighting passive system results in a very simple, effective and low cost solution that can be easily applied in economically emerging countries. The most important fact is that high illuminance levels are achieved and, simultaneously, there is important energy reduction, taking advantage of natural light instead of competing with sun power.

INTRODUCTION

Urban commerce and storefronts play a major role in the economy and the very image of a city, especially in climates that favour exterior human activities. Being a fundamental element of the commercial process, a proper visual presentation of shop windows is crucial. Lighting contributes to the creation of a corporate identity, ideally, it assists the production of the image desired by the trader and together with other components of the design it contributes to sales promotion (Rea, 2000). The present study analyzes the lighting requirements and visual inconveniences of window displays associated with the Mediterranean climate and how they are or should be dealt with, so that the aesthetic and commercial function of shop windows will not be inhibited.

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The complexity of light presentation of these everyday urban elements is linked to their exposure to varying light conditions in the outside environment. Being a part of the urban landscape, the illuminance levels in the interior of shop windows should be corresponding to the surrounding light, so that they would be able to stand up and yield good vision of the products on display. In Mediterranean climates, the temperature favours urban commerce, since duration of daily solar radiation is extensive and solar intensity is prevalent throughout the whole year. As a result of the very high level of exterior illuminance, though, the visual goals of window displays are often impeded.

High energy consumption yet poor visual outcome

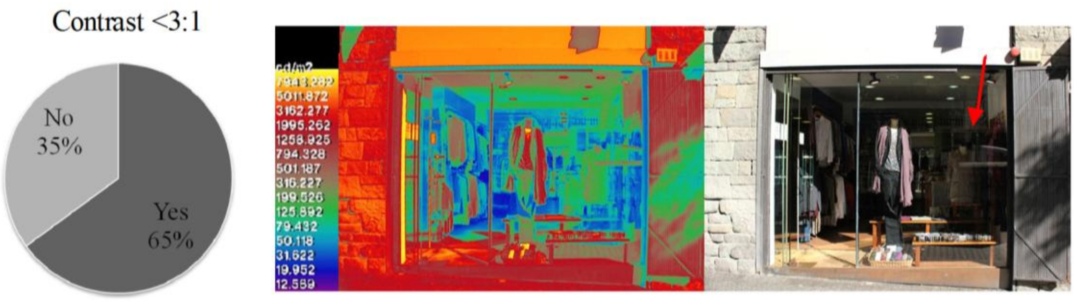
The lighting design of window displays is required to perform multiple visual tasks, most important of which are to attract clients and to provide visual comfort and good vision of the products exhibited. In order to do so, two basic factors, among others, must be secured: adequate illuminance levels and luminance contrast between the display objects and their background. A recommended value for luminance ratio between the illuminated object and its surrounding area is 3:1, although this ratio can reach values from 10:1 to 30:1 (Carillo, et al., 2010). Regarding illuminance values, they can be as high as 5.000 lx during night-time and 10.000 lx during daytime (Freyssinier, Frering, Taylor, Narendran, & Rizzo, 2006). Moreover, certain studies prove that a higher illuminance level implies that more passers-by are attracted by the shop windows (Carillo, et al., 2010). As a result, the consumption of energy for the lighting of window displays that remains on for at least 15 hours per day (Freyssinier, Frering, Taylor, Narendran, & Rizzo, 2006) is rather high.

In Catalonia, window display lighting constitutes 11.2% of the total energy consumption for the lighting of a typical store (Institut Catalá d´Energia, 2008). Nevertheless, despite the high energy consumption, visual inconveniences insist; during the research discussed in this paper, a study of a representative sample of shop windows of Barcelona has been performed in its natural opposing lighting conditions, day and night, analyzing their visual results. The basic tools of this analysis have been the luminance maps and evaluation, via computer application, of the odds of glare and its possible sources. The study has confirmed and identified the main inconveniences that can impair the visual result and, therefore, the commercial purposes, during daytime hours. Specifically, the most frequent problems are: penetration of exterior light into the scene, which affects the balance of the luminances projected, failure to reach the appropriate contrasts for the projection of exhibits, as well as glare and annoying reflections.

Among the analysed stores, **as shown in Figure 1**, the visual presentation of 65% of them failed to reach a contrast of 3:1 between all exhibits and their surroundings, as well as 65% of them failed to avoid annoying reflections. In addition, the conducted analysis confirms that the commercial storefronts mostly affected by such inconveniences, especially by the generation of glare, are those receiving direct solar incidence, even in cases that solar protection is provided. This effect can be generated not only by solar incidence in the actual presentation of the window, but also by the incidence in immediately adjacent areas, whether on the surrounding facade or the sidewalk that lies before it.

In order to help face these visual disadvantages resulting from very high levels of exterior illuminance, a remedy often applied is to increase artificial illuminance projected during the day, in contrast to the one projected overnight. However, the intensity of sunlight in low latitude areas is so high that artificial lighting can never compete with the natural one. The inability of artificial lighting to compete with high solar illuminance makes it vain for any power to increase during the day, along with the corresponding energy additional charge this practice entails.

This new study, instead, evaluates the benefits of the use of a passive design that takes advantage of the very solar ray incidence in order to increase interior illuminance effectively and at the same time reduce energy consumption.



a)

b)

Figure 1 *(a) Part of examined window displays that failed to reach contrast 3:1 between all exhibits and their surroundings, plus an example (b) Part of examined window displays with annoying reflections, plus an example.*

METHODOLOGY

The present research evaluates the visual and energetic benefits of an innovative passive design that obstructs solar rays and redirects them into the interior of the shop window scene. In fact, the improvement of the quality of the observation of exhibits during daytime is assessed, along with the possible reduction in energy consumption.

The research implementation is summarized in 4 main steps which are presented below and explained in the following subsections:

1. Design of a component that manages to obstruct solar radiation and re-direct it towards the interior of the scene.

2. Development of two scale models of the window analyzed, the one being independent of and the other one based on the proposed system.

3. Simulation of the unfavourable exterior light conditions.

4. Analysis of visual differentiation of the window display in the same lighting conditions, depending on the existence of the proposed system, or not.

Development of the passive design component

A typical window display of Barcelona has been selected among the sample observed, that is about four meters high and one meter wide. Based on the solar diagram of the city, several design tests of a system of reflective surfaces have been performed in order that, when the latter is incorporated in a typical window facing south, it could make the most of the solar incidence during the most unfavourable conditions; these are produced during summer solstice, as it has been confirmed after analysis in a simulation program that incorporates solar trajectories (Heliodon). The possible contribution of both flat and curved reflective surfaces was examined in various positions, with the purpose of introducing into the showcase as much light as possible, especially during summer.

The design finally proposed here, is based on two successive light reflections, **as shown in Figure 2**, where typical dimensions can also be appreciated. Rays that fall upon the curved surface will be reflected symmetrically around the axis joining the point of incidence and its centre of curvature (Peoglos, Raptis, & Christodoulides, 2004); subsequently, they will be cast on the plane surface and will be reflected towards the interior of the scene. Regarding the concave surface, in order to directly introduce as much light as possible, the use of a specular material is proposed. On the contrary, for avoiding intense reflections in the scene that, depending on sky conditions, may adversely affect the visual result, the use of a diffuse-reflection surface is proposed for the second reflection.

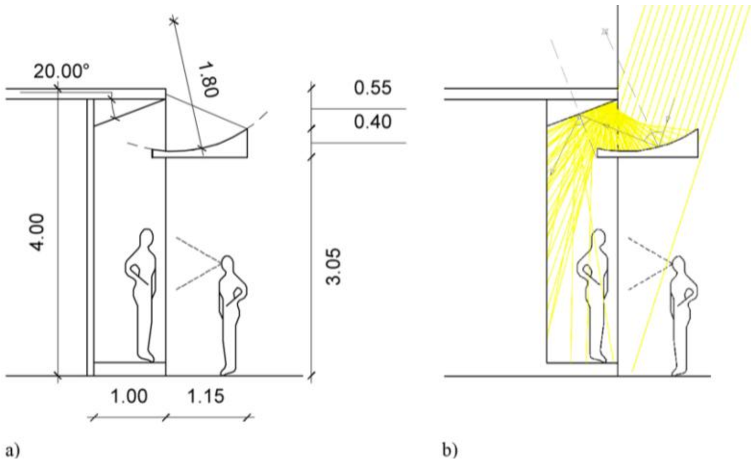


Figure 2 (a) Geometry of the component proposed (b) Conduction of natural light in the interior of the scene.

A vertical movable lamina should be placed in order to control the system and, depending on the solar height, to regulate the solar radiation introduced through the opening of the system. In addition, a fixed glass surface could help to avoid problems of water or dirt accumulation. In any case that this design is implemented, it will have to adjust to any special needs.

Development of the scale models

Two scale models of the window analyzed, the one being independent of and the other one based on the proposed system, have been developed. As in the present study the effect of chromatic contrast is not analyzed, all the components of the scene have been chosen to be of soft and slightly contrasting colours. The dimensions of the models have been adjusted to the artificial lighting projected, giving special care so that both the area of the surfaces and the luminous flux they receive, would be correctly scaled.

In each one of the models two LED sources have been placed above two mannequins and 30cm of led stripe above the background of the scene, **as shown in Figure 3**. Because of their size and characteristics, the sources Prolight PM2B 3LxS-SD-3W Power LED have been chosen; in order to simulate the illuminance of the real window display, after measuring their luminous intensity and applying the basic laws of photometry, the appropriate scale of the model has been defined:

$$dM = 0,09\ dR \quad (1)$$

For wall washing lighting simulation, a strip led of 40W type 3528 has been used in each model. A potentiometer has also been connected to it, so that its intensity could be dimmed and, in this manner, possible reduction of energy for vertical illumination could be evaluated.

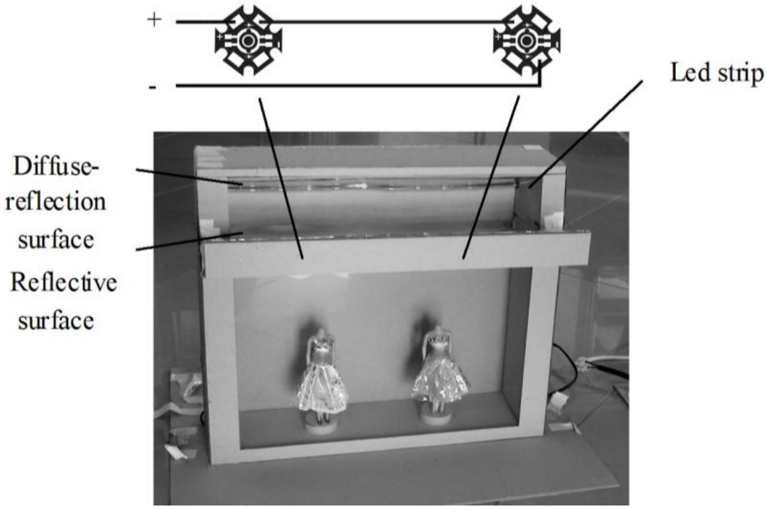


Figure 3 *Model based on the system proposed.*

Simulation of the desired exterior light conditions

The study took place in Athens on December 10, during the time of zenith. In order to simulate the summer solstice in Barcelona (72° during the zenith) the table where each model was placed has been rotated through 43°, **as shown in Figure 4**, equal to the difference of solar altitude on December 10 in Athens (29^o during the zenith). Furthermore, in order to obtain an overall assessment of the results for the entire year, a simulation of the equinox and winter solstice in Barcelona (49º and 26º correspondingly during the zenith) were simulated rotating the table through 20º, and -3º correspondingly.

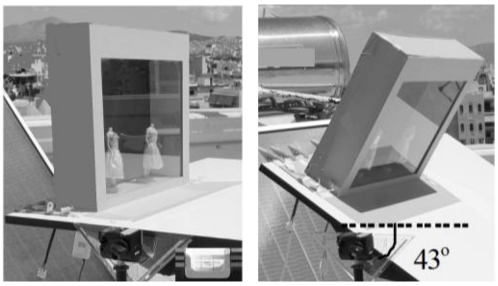


Figure 4 *Simulation of the desired exterior lighting conditions by rotating through 43^o the table where the model is placed.*

Evaluation of visual differentiation, dependeding on the existence of the proposed system

The comparison of the visual outcome of the two different models has been realized via the observation of photographs and their equivalent luminance maps, in addition to the observation in situ. The comparison took into account the following visual inconveniences:

1. Annoying reflections.

2. Achievement of 3:1 contrast between products and their surrounding area.

3. Glare.

In order to compare the possibility of glare in every situation, the Radiance based tool, called Evalglare, which evaluates that possibility through the daylight glare probability index, DGP (Wienold, 2009) has been used in addition to the luminance maps.

RESULTS AND DISCUSSION

Improvement of visual appeal

The comparison of the visual result of the two scenes, the one being independent of and the other one based on the proposed system, has resulted in the expected improvement. Via the observation of the photographs and the luminance maps deriving from them, the positive effect of the redirection of the sunlight into the scene is appreciated, **as shown in Figure 5**. Specifically, when comparing the two models, the following parameters are observed:

1. The annoying reflections on the glass of the scene, after the incorporation of the proposed system, are significantly moderated. Looking at the model without the system (on the left) one can see the reflection of the photographer´s figure; however, looking at the model with the proposed design incorporated (on the right) this effect does no longer exist.

2. The desired contrast of 3:1 between the products and their surrounding area is achieved in the model where the proposed system has been incorporated, while simultaneously solar incidence upon products is avoided.

3. Large surfaces of high luminance that can dazzle there are in the model where the proposed design is not used; on the contrary, in the model based on the proposed system the area and luminance of these surfaces is moderated, thus glare is less probable. The comparison of the DGP index in the two cases is indicative of the improvement.

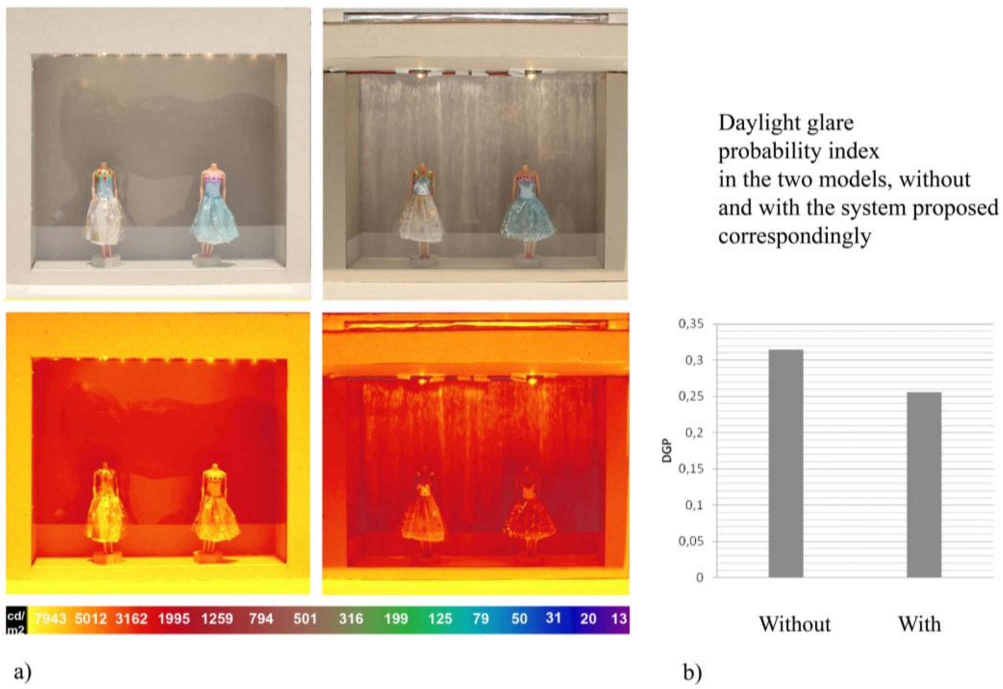


Figure 5 (a) Photograph and luminance map (b) DGP index. Comparison of the two models, without (left) and with (right) the system proposed.

Concerning the rest of the seasons, the design proposed has no negative effects. Instead, during the research discussed in this paper, the effect against the inconveniences of glare and annoying reflections has been examined and proven positive throughout the year.

Energy demand reduction

As predicted, the visual result of the model, following the incorporation of the system proposed is significantly improved. That alone signifies that the frequently applied technique of increasing the power of the lighting of window displays, is a remedy that can be abandoned along with the useless energy charge it entails; therefore, energy consumption for the lighting of display windows can be reduced.

In addition, the possibility of further energy reduction has been verified with the help of the potentiometer connected to the vertical illumination of the model: The illuminance of the background lighting of the scene has been decreased, in the case of the design proposed, to the 1/3 of the illuminance projected before. Once again, when examined in the simulated lighting conditions, even with a drastic reduction of power applied the result has been positive, **as shown in Figure 6**. The comparison of the visual result of the two scenes, the one being independent of and the other one based on the proposed design with a power decrease to the 1/3 for vertical lighting, has resulted in improvement. Specifically, when comparing the two models, the following parameters are observed in the one based on the system proposed despite the power reduction:

1. The reflections of the glass of the scene are, once again, significantly moderated.
2. The desired contrast of 3:1 between the products and their surrounding area is achieved, while solar incidence upon them is avoided.
3. Fewer areas of high luminance that can dazzle are generated. The comparison of DGP index in the two cases is indicative of the improvement.

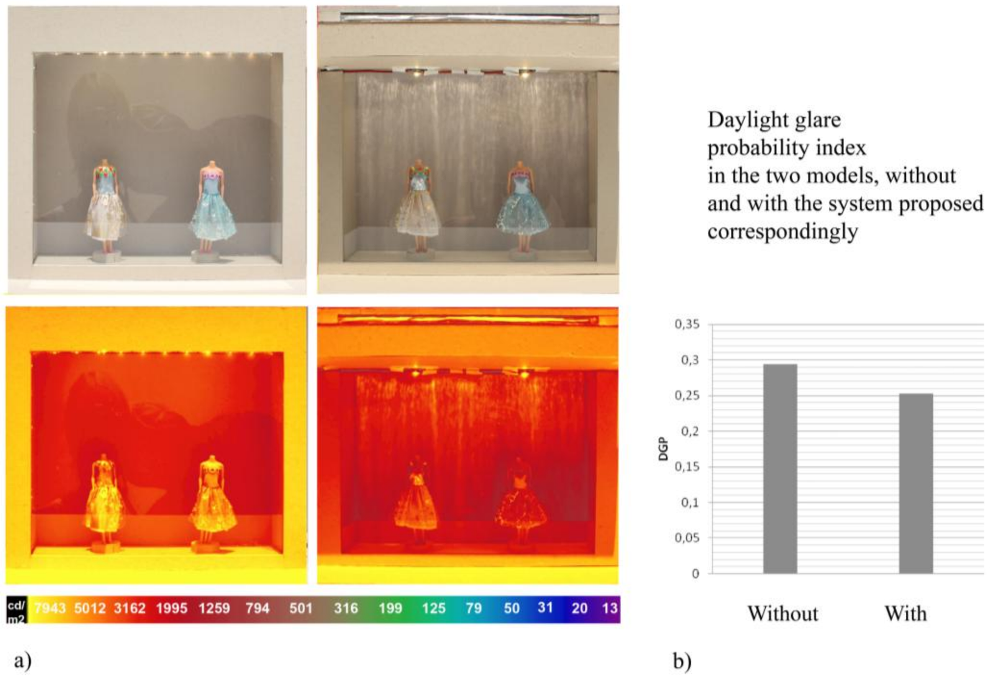


Figure 6 (a) Photograph and luminance map (b) DGP index. Comparison of the two models, without (left) and with (right) the system proposed when wall wash lighting is reduced to 1/3.

The effects observed above are the expected ones, since solar light intensity which is introduced in the scene, and not artificial lighting, is the one increasing significantly the illuminance in it. In that way, it is verified that under the most negative conditions for the visual result of shop windows, which arise during solar incidence, not only does the vertical lighting not have to be increased but, in contrast, it can be drastically reduced while, simultaneously, the visual outcome can be significantly improved.

CONCLUSION

This paper results in a passive design proposal that can offer very positive effects on the visual result of shop windows, improving the quality of their observation, thus fulfilling their commercial visual goals during the day and, in addition, reducing energy consumption. In low latitude countries, the inability of artificial lighting to compete with high solar illuminance makes it vain for any power to increase during daytime, along with the corresponding energy charge this practice entails. Instead, the increase of interior illuminance levels of shop windows by using the very illuminance of the sun may improve the visual outcome and reduce energy consumption for the lighting of the scene.

The positioning of the proposed design of sunlight redirection, with the dual effect of both obstruction of its incidence and the benefit of its intensity to increase illuminance in the interior of the shop window, has very positive effects on its visual presentation, especially in terms of reducing annoying reflections and the possibility of glare. Moreover, these effects are valid even when reducing the installed power for the lighting of the background of the scene, thus making possible, in combination with the use of sensors and resistors, further reduction of energy consumption for the lighting of the display window. This new lighting passive system results in a very simple, effective and low cost solution that can be easily applied in economically emerging countries, with considerable environmental and economic benefits when incorporated in the highly energy-consuming display windows. Therefore, it is deduced that, instead of trying to compete with the sun, it is better for one to ally with it.

ACKNOWLEDGMENTS

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NOMENCLATURE

d_M = dimensions of the model

d_R = dimensions of the real window display

DGP = Daylight Glare Probability

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Developing Bioclimatic Zones and Passive Solar Design Strategies for Nepal

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ABSTRACT

Nepal displays a highly varying topography which is leading to a variety of climatic conditions. With the introduction of modern construction technologies in the country, the building sector has adopted uniform design and building techniques that often neglects local climate and rely on energy-intensive mechanical means to provide thermal indoor comfort. The definition of a climate classifications for building design can be an important decision making tool towards climate-responsive and energy-efficient architecture. This paper represents the groundwork for developing bioclimatic zones for building design in Nepal. Based on climatic maps areas of similar climatic conditions were identified. Climate data of various locations within these zone were collected and analysed. A bioclimatic approach was adopted using the psychrometric chart in order to identify passive design strategies for each locations. Finally, an overview of appropriated design strategies for summer and winter for each zones is developed.

INTRODUCTION

Climate-responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development (Szokolay, 2008). However, architects and building planners are still guided by universal design style that is rather focusing on form language and neglecting the local climate conditions (Liedl, Hausladen, & Saldanha, 2012). Climate classification for sustainable building design can fill the gap and guide building professionals which design strategies are suitable in a certain climate context. Many countries that have a variety of climates within their territory have developed a climatic classification for building design - also called bioclimatic zoning. Climate maps for Nepal have been developed based on physiological features and vegetation. However, no building design specific climate zoning is available for the country. Few authors identified the climate-responsive design strategies for specific locations in the country (Upadhyay, Yoshida, & Rijal, 2006). This research is the first comprehensive study aiming to provide the groundwork for developing a bioclimatic zoning and the appropriate design strategies for the whole territory of Nepal.

There are several approaches to define a climate classification for building design. Givoni (1969) distinguishes between four main climate classes, namely hot, warm-temperate, cool-temperate and cold climates; using sub classification he elaborated a total number of eleven climate types for the whole planet. Koenigsberger (1974) developed six climate zones for building design in the tropics based on the two climate factors, temperature and humidity; these factors dominantly influences thermal comfort. Many countries with high climatic variations have developed their own climate zones for building design which is often used for defining thermal performance standards for buildings. There is no universal approach for the definition of such a zoning. Most classifications use climate variables (such as temperature, humidity, precipitation, solar radiation, wind conditions) as main criteria (Table 1). Building design factors, e.g. heating and cooling degree day, effective temperature, temperature swing or passive design strategies, are often used as secondary criteria or in combination with climate variables. There are two countries (Argentina, Brazil) that have used only passive design criteria to define the bioclimatic zoning. In some classifications topographical criteria like latitude, longitude, altitude and distance to the coast are added to differentiate bioclimatic zones. Most classifications use the bio-climate chart to identify passive solar design strategies for the different zones.

The way of defining climate classification is from country to country different and few interesting examples are described in detail in the following. USA's climate zones are developed based on the need for heating and cooling using the amount of heating degree days (HDD) and cooling degree days (CDD) (ASHRAE, 2007). China uses the mean temperature in the hottest and coldest month as main criteria. Complementary criteria is the number of days that average temperature is below 5 °C or above 25 °C (Lam, Yang, & Liu, 2006). For the development of the Indian zoning monthly climate data of mean temperature, relative humidity, precipitation and number of clear days were analysed from 233 meteorological stations of the country (Bansal & Minke, 1988). Defined climate conditions must prevail for more than six month; otherwise the location is classified as composite climate. Brazil, being the fifth largest country on the globe with a range in latitude of about 40°, has developed bioclimatic zones adopting the bioclimatic chart from Givoni for hot developing countries. Climate data from 330 locations was plotted on the chart to identify passive design strategies for each location. According to the predominant design recommendations these locations were grouped into different climate classes resulting into eight bioclimatic zones (ABNT, 2003). Argentine has used three indicators to define the zoning: 1. Heating degree days (HDD); 2. Effective temperature (ET) on a typical summer day; 3. Average daily thermal swing for the relevance of thermal mass. The HDD is a key indicator for the heating demand in winter dividing the country in the six main zones. The temperature swing being an indicator for the incorporation of thermal mass is used to classify the four warmer zones into 12 sub-zones. The two colder zones are sub-classified indicating the potential for passive solar heating

Table 1. Climate Classifications for Building Design and Used Criteria

Target region	Used criteria			Source
	Climate	Passive design	Topography	
World	X			(Givoni, 1969)
Egypt	X			(Mahmoud, 2011)
India	X			(Bansal & Minke, 1988)
USA	X	X		(ASHRAE, 2007)
China	X	X		(Lam et al., 2006)
California	X	X		(The Pacific Energy Centre, 2006)
Tropics	X		X	(Koenigsberger, 1974)
North-east India	X		X	(Kumar, Mahapatra, & Atreya, 2007)
Chile	X		X	(INN, 1977)
World	X	X	X	(Liedl, 2011)
Peru	X	X	X	(Chang Escobedo, 2008)
Venezuela	X	X	X	(Rosales, 2007)
Brazil		X		(ABNT, 2003)
Argentine		X		(IRAM, 1996)

METHODS

Research region

Nepal expands from the Gangetric plain at an elevation of 60 m up to the high Himalaya Mountains with the highest peak in the world the Mt. Everest at an elevation of 8,848 m. The highly diversified geography leads to large variation in climate. The climatic diversity has been also reflected in the traditional architectures. While traditional houses in the upper Himalayan have a compact building typology and are attached to each other aiming to reduce heat loss, houses in the subtropical plain have a more elongated floor plan and are distributes in loose settlement pattern allowing air penetration (Bodach, Lang, & Hamhaber, 2014).

With the modernisation of the constructions sector in Nepal, traditional building techniques are replaced by universal design, modern construction technologies and materials. New buildings in urban centres of Nepal are built using column-beam structure of reinforced concrete combined with brick filling walls and flat roofing. Facades with large unshaded glazing area and aluminium panel cladding are typical design options for commercial buildings. Due to centralisation and issues of prestige, modern building practises from the capital Kathmandu are spreading out in other parts of the country where the climatic conditions are very different. Architects and engineers are trained in the capital or in India bringing design ideas and construction techniques from these places that are often inappropriate in the climate of the place.

In contrast to other Asian countries, Nepal has not developed any standards or regulation for a more sustainable building design. The national building code is concerned about structural safety and does not contain any standards on energy efficiency. Currently, the Department of Urban Development and Building Construction (DUDBC) which is the government organisation responsible for drafting building regulation, has started the process to develop green building technology guidelines. However, the lack of a proper bioclimatic zoning makes it difficult to define standards for climate-responsive building design or envelope insulation. A climate classification for building design will be a useful tool for regulators as well as building professionals to enhance climate-adapted design practices and the step forwards towards a more sustainable development of the Nepalese building sector.

Bioclimatic approach and thermal comfort

The bioclimatic approach explores the opportunities to design according to the local climate conditions. Olgyay (1963) developed the first bioclimatic chart based on outdoor climate conditions aiming to identify mitigation measures like solar radiation, air movement or shading to achieve a comfortable indoor climate. Givoni (1963) developed a bioclimatic chart based on indoor conditions using the standard psychrometric chart. His chart has been widely used to identify passive design strategies for different bioclimatic zones (Lam et al., 2006; Rakoto-Joseph, Garde, David, Adelard, & Randriamanantany, 2009; Singh, Mahapatra, & Atreya, 2007). Some countries have used solely his chart to define the climate classification for building design (ABNT, 2003).

The main challenge for developing a bioclimatic chart is the definition of the thermal comfort zone. Thermal comfort is defined as a subjective response of a person in regard to satisfaction with the thermal environment (ASHRAE, 2010). It is influenced by environmental factors, such as air temperature, air movement, humidity, radiation, and personal factors like metabolic rate, clothing, state of health and acclimatization (Szokolay, 2008). For naturally ventilated buildings ASHRAE Standard 55 proposes the adaptive thermal comfort approach and defines a range of acceptable indoor temperature of 2.5 K above and below optimum comfort temperature. Thereby, the comfort temperature is calculated by the outdoor temperature using the equation (1).

$$T_c = 0.31T_{out} + 17.8$$ (1) (de Dear & Brager, 2002) where T_c is the optimum comfort temperature and T_{out} is the mean outdoor temperature

However, some studies question the applicability of the adaptive model, particularly, in warm and humid climates (Harimi, Ming, & Kumaresan, 2012). Two studies on thermal comfort in Nepal have found that people feel comfortable at temperatures far below and above international comfort standards (Rijal, Yoshida, & Umemiya, 2010). Comparing the optimum comfort temperature using equation (1) and the actual comfort temperature found in the field, temperature differences between 0.2 and 9 K are recorded depending on the region (Table 2). That means the adaptive thermal comfort model of ASHRAE 55 might be not applicable to Nepal.

Table 2. Comparison of predicted comfort temperature and actual found in the field

Location	Altitude	Summer $T_{mean\ out}$	Summer $T_{c\ pred}$	Summer $T_{c\ field}$	Winter $T_{mean\ out}$	Winter $T_{c\ pred}$	Winter $T_{c\ field}$
Banke	150 m	31.4	27.5	30.0	15.2	22.5	16.2
Bhaktapur	1,350 m	22.2	24.7	25.6	10.6	21.1	15.2
Dhading	1,500 m	25.4	25.7	29.1	13.3	21.9	24.2
Kaski	1,700 m	18.8	23.6	23.4	8.9	20.6	18.0
Solukhumbu	2,600 m	13.1	21.9	21.1	4.0	19.0	13.4
Mustang	3,705 m	n.s.	n.s.	n.s.	6.0	19.7	10.7

$T_{mean\ out}$ **Mean outdoor temperature** (Rijal et al., 2010)
$T_{c\ pred}$ **Predited comfort indoor temperature** (de Dear & Brager, 2002)
$T_{c\ field}$ **Comfort temperature according to field study** (Rijal et al., 2010)

Updating his original research work, Givoni proposed an extended comfort zone for hot developing countries that considers the acclimatization resulting from living in naturally ventilated buildings (Givoni, 1992). It defines temperatures between 18°C and 29°C and humidity levels from 4g/kg up to 17g/kg as comfortable. Givoni's extended comfort zones is used in this study because it is evaluated the most appropriate approach for the Nepalese context. Givoni did not define zones for passive design strategies in his updated chart for hot developing countries. Therefore, this study uses the boundaries defined by Gonzalez et al (1986) for warm and humid climates in developing countries. The upper limit for ventilation is set to absolute humidity of 20.5 g/kg. The ventilation zone was extended to 100% of relative humidity taking reference to several studies conducted in hot and humid climates that found out that local people can cope with higher humidity by increasing ventilation (Gonzalez et al., 1986; Shastry, Mani, & Tenorio, 2012). Solar passive heating zone is defined between 10.5°C and 20.0°C (outside comfort zone). Mechanical heating is needed up to a temperature of 10.5°C. The upper boundary for evaporative cooling is set at the wet bulb temperature line of 24°C. Humidification is needed below wet bulb temperature of 10.6°C.

Nepal's climatic diversity is mainly caused by the high variation in altitude. Therefore, elevation was chosen as the main criteria for developing bioclimatic zones. Meteorological data (temperature, precipitation) from 26 weather stations were collected either directly from Department of Hydrology and Meteorology or derived from United Nation's Food and Agriculture Organisation (FAO) climate database (FAO, 2014). The station data was used to generate a typical meteorological year (TMY) for each location using the recognized software tool METEONORM (Meteotest, 2014). The TMY was then analysed using the bioclimatic approach.

RESULTS

The plotting of the climate data of 26 locations on the psychrometric chart shows clearly that Nepal has a composite climate that is strongly influenced by the monsoon. Composite means there is no dominating climate for six following months. Instead there are four different seasons that are leading to different design strategies: 1. Winter season (December to February); 2. Pre-Monsoon (March to May); 3. Monsoon or summer season (June to September); 4. Post-monsoon (October to November).

The analysis of the bioclimatic chart of 26 locations led to four different bioclimatic zones (Figure 1): 1.Warm Temperate (below 500 m); 2. Temperate (500-1500 m); 3. Cool temperate (1501-2500 m); 4. Cold (above 2500 m). Table 4 gives an overview about the climatic conditions in each zone. The climate and design strategies for each zone are discussed in the following.

In the warm temperate climate daily temperature rises in pre-monsoon and monsoon season well above the comfort zone reaching up to 35°C. While relative humidity is below 60 % in the pre-monsoon, it increases up to 90 % in monsoon season. The winter month are warm with average temperatures above 10°C. Figure 2 shows that the main design strategies for warm temperate climate zone is natural ventilation in summer and passive solar heating in winter. For the pre-monsoon time thermal mass is recommendable.

Table 4. Characteristics of different bioclimatic zones of Nepal

Bioclimatic zones	Warm temperate	Temperate	Cool Temperate	Cold
Summer temperature				
Mean maximum	29 – 35°C	25–35°C	22 – 26°C	16 – 22°C
Mean minimum	22 – 26°C	18–25°C	14 – 18°C	7 – 12°C
Winter temperature				
Mean maximum	21 – 26°C	17 – 25°C	11 – 20°C	below 10°C
Mean minimum	9 – 15°C	5 – 10°C	-2 – 5°C	below -2°C
Relative Humidity	25 – 90%	20 – 90%	30 – 90%	10 – 90%

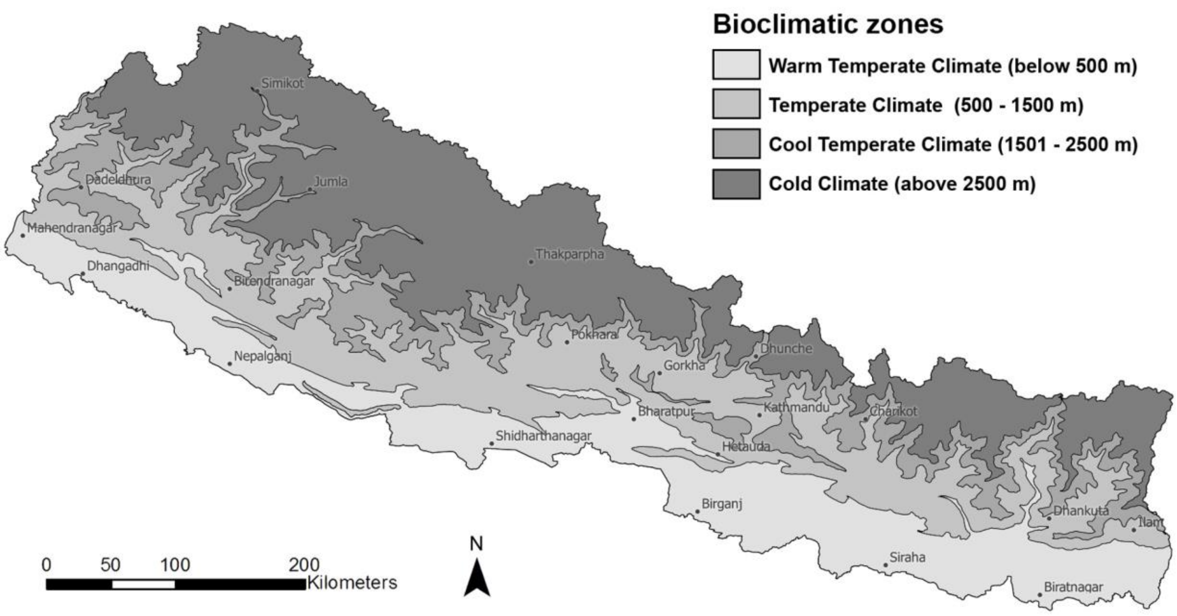

Figure 1 *Bioclimatic zoning for Nepal*

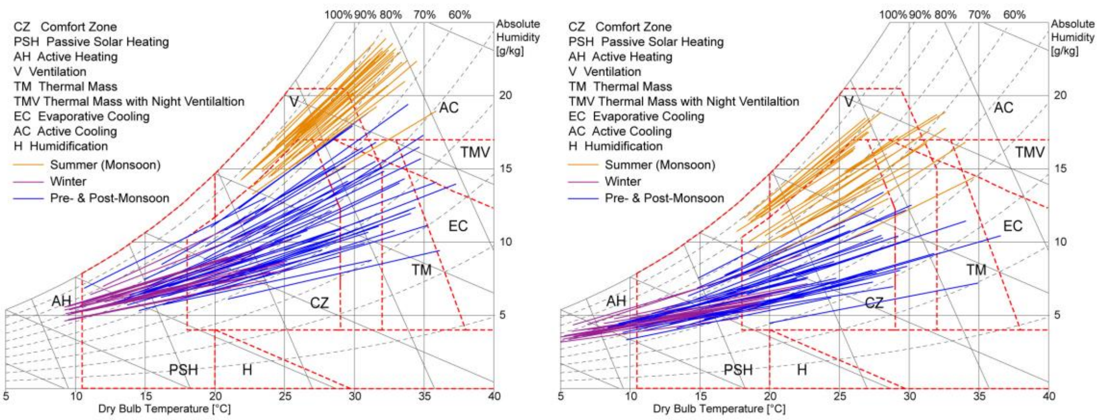

Figure 2 *Bioclimatic chart for warm temperate (left) and temperate climate zone (right)*

In the temperate climate zone average summer temperatures are more moderate, hardly exceeding the comfort zone. During pre-monsoon mean temperatures and humidity is very much comfortable. However, in some places day temperature can rise up to 35°C. In the monsoon season relative humidity might increase above 80% in few locations. In winter temperatures fall below the lower comfort limit;

night temperature can drop down to 5°C. However, day temperature might fall within the comfort zone around 20°C. The most important design strategy for the temperate climate zone is passive solar heating combined with thermal mass (Figure 2). This strategy can balance the high temperature swing during the colder months of the year. Few mechanical heating might be necessary in winter. During monsoon season ventilation is required. Thermal mass can bring relieve and absorb excessive heat in pre-monsoon season.

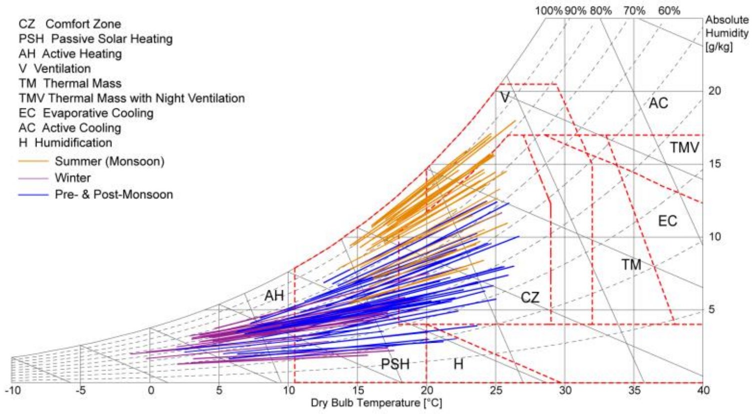

Figure 3 *Bio-climatic chart for cool temperate climate zone*

In the cool temperate climate day temperature in pre-monsoon and monsoon season are within the comfort zone. During monsoon time temperatures are between 15-20°C and relative humidity rarely rises above 80%. In winter average temperatures are clearly below comfort. Night temperatures can down up to the freezing point. Passive solar heating is the most essential strategy used all over the year (Figure 3). In summer thermal mass that store solar heat gain during the day might compensate night temperatures that are often below the lower comfort limit. In winter solar heat gains might contribute to reduce the heating demand by mechanical means. However, mechanical heating is necessary from October to March.

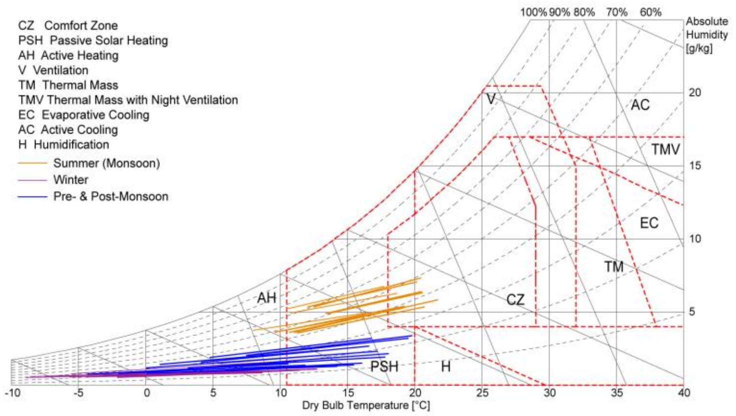

Figure 4 *Bio-climatic chart for cold climate zone*

In the cold climate temperature hardly reach the comfort zone (Figure 4). During summer, day time temperature rarely rises above 18°C. During winter average temperature are around the freezing point. In the cold climate of Nepal passive solar heating is the only design strategy that can be applied. It will reduce the heating demand during the summer month. However, mechanical heating is required all over the year.

DISCUSSION

The bioclimatic chart for the warm temperate climate indicates passive solar heating as main climate-responsive design strategy in winter. By capturing the solar radiation during the day and storing the heat in the thermal mass of the building, lower night temperature can be compensated. By this way mechanical heating is not required. Thermal mass is also desirable during the pre-monsoon for cooling purpose. In contrast the warm and humid summer claims for light building materials like applied in the traditional architecture of the region. The solution to this conflicting design strategies might be the application of high thermal mass in the interior of the building, e.g. for interior walls, floors and ceilings. A suitable construction technique for the exterior walls could be the reverse brick veneer wall. High thermal mass of the northern outside wall without solar exposure is also possible. In any case shading of the openings and the construction elements of high thermal mass has to be provided in summer to avoid overheating. Furthermore, building design should enhance air movements within the building through cross or stack ventilation.

The temperate climate zone is the most comfortable bioclimatic zone of Nepal. Passive solar heating combined with the minimisation of air filtration and good insulation of the building envelope can fulfil most of the heating demand in winter. High thermal building mass is desirable for passive heating as well as passive cooling due to the high daily temperature swing. Enhancing natural air movement through cross or stack ventilation is required during the warm and humid monsoon season.

In cool temperate climate of Nepal passive solar heating strategies is required all over the year. Building layout should be compact and of high thermal mass. Optimising the design for passive solar heating can reduce the amount of mechanical heating. High solar radiation available in winter can also be used for active solar heating by using solar thermal collectors of solar air heating.

The only bioclimatic design strategy in cold climate of Nepal is passive solar heating. However, active heating is needed all over the year. Compact building layout, reduction of air infiltration and good insulation of roof, walls and windows are the imperative to protect from the cold in this harsh mountain climate. The application of active solar heating to support a conventional heating system is recommended.

CONCLUSION

This study developed the first bioclimatic zoning for Nepal. The main passive solar design strategies for the four different bioclimatic zones were identified using the bioclimatic chart. This new climate classification can help planners and architects to make general decisions at early design stage to develop more climate-responsive and energy-efficient buildings. Furthermore, it might be useful for the development of appropriate building energy regulations.

However, the qualitative approach of the bioclimatic chart has its limitations due to the fact that it only considers two climate factors: temperature and humidity. The micro-climatic conditions can vary and a detailed analysis of the site might be necessary to come up with site-specific solutions.

Due to the fact that the climate in Nepal is of composite character design strategies might conflicting each other. Therefore, further research is needed to quantify the effectiveness of the passive design strategies in each climate zones.

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Session 2B : Low carbon cities and neighborhood development

PLEA2014: Day 1, Tuesday, December 16
14:10 - 15:50, Compassion - Knowledge Consortium of Gujarat

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Improving Pedestrian Thermal Comfort by Pavement-Watering during Intense Heat Events

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ABSTRACT

From the late 19th until the mid-20th Century, pavement-watering was used to prevent dust cloud from forming. This practise has since been lost, but is now stirring new interest as a tool for urban heat island mitigation, climate change adaptation and pedestrian thermal stress reduction. To evaluate the potential of pavement-watering, two daytime watering methods were tested over the summer of 2013 in Paris, France: the pavement and sidewalk of a N-S street and the pavement of an E-W street. The effectiveness of the method was measured according to mean radiant temperature (MRT) and Universal Thermal Climate Index (UTCI) equivalent temperature reductions, determined by a statistical analysis. MRT and UTCI reductions were observed at both sites. While daily effects were highest at the N-S site, highest maximum hourly cooling was observed at the E-W site, reaching 2.9°C for MRT and 1.2°C for UTCI. Overall, hourly cooling was most often statistically significant at night and at the N-S site.

INTRODUCTION

Paris' strong hygienist movement during the 19th Century led to the development of its dual water supply. Street cleaning has since relied on the use of non-potable water. Until the mid-20th Century, streets could be watered up to five times a day on hot summer days to prevent dust clouds from forming (Girard, 1923). According to reports by urban managers at the time, many inhabitants also it had a cooling effect. As mechanized cleaning was generalized, these practises were lost and nearly forgotten.

Urban areas, through a combination of radiation trapping, wind obstruction, and low surface humidity, create a localized warming effect know as the urban heat island effect (Grimmond, 2007; Oke, 1973). Today, climate change is expected to increase the frequency and intensity of heat-waves on all continents, including in the Paris region (Lemonsu, Kounkou-Arnaud, Desplat, Salagnac, & Masson, 2012). Unfortunately for urban dwellers, heat-waves have been found to interact with urban heat islands and increase their intensity (Li & Bou-Zeid, 2013). This mechanism helps explain why heat-waves are more devastating in densely populated cities than in rural areas, such as was the case in Paris during the August 2003 heat-wave (Robine et al., 2008). Adaptation to more frequent and more intense heat-waves is therefore crucial in dense cities.

In this context, pavement-watering may once more have a role to play in cities as an emergency counter-measure against heat-waves. By artificially reintroducing the evaporative mechanism at work in rural soils, pavement-watering is expected to positively impact pedestrian thermal comfort by reducing surface and air temperatures, while only marginally increasing air humidity.

In Japan, field and numerical studies of pavement-watering have been carried out over the last twenty years or so (Kinouchi & Kanda, 1997, 1998; Nakayama & Fujita, 2010; Nakayama & Hashimoto, 2011; Takahashi, Asakura, Koike, Himeno, & Fujita, 2010; Yamagata, Nasu, Yoshizawa, Miyamoto, & Minamiyama, 2008). In Paris, computer simulations of the method at the city-scale (Météo-France & CSTB, 2012) have been conducted in recent years as well as pavement-watering field experiments (Bouvier, Brunner, & Aimé, 2013).

Review of previous field work reveals strong variability in the micro-climatic effects of pavement-watering as well as in their measurement methodology. Reported air cooling ranges from 0.4°C to 4°C, while measurement heights vary from 0.5 m to 2 m (Bouvier et al., 2013; Takahashi et al., 2010; Yamagata et al., 2008). Furthermore, only a few studies study the effect on pedestrian thermal comfort. This variability in methods only highlights the need for standardization in urban micro-climatic measurements as was outlined by Johansson, Thorsson, Emmanuel, & Krüger (2014).

To better understand the potential of pavement-watering to improve pedestrian comfort in Paris, two watering methods were tested over the summer of 2013 at two locations: rue du Louvre in the 1st and 2nd Arrondissements and Belleville in the 20th Arrondissement. This article will present the method used to analyse field measurements and the effects of pavement-watering on pedestrian thermal comfort as estimated by mean radiant temperature (MRT) and the Universal Thermal Climate Index (UTCI).

MATERIALS AND METHOD

Micro-climatic parameters were investigated at two sites in Paris, France over the summer of 2013, hereafter referred to as Louvre and Belleville. For the former, measurements were conducted on rue du Louvre, near Les Halles in the 1st and 2nd Arrondissements, while at Belleville they took place on rue Lesage and rue Ramponeau in the 20th Arrondissement. Watered and control weather station positions are illustrated in Figure 1. Two twin weather stations were positioned for each site, each pair measuring identical parameters. Each position was chosen to ensure that the urban environment of each station was as identical as possible (traffic, materials, urban morphology, sky view factor, …).

On rue du Louvre, watering took place on the sidewalk and pavement, each paved with asphalt concrete. Both watered and dry portions of the street are approximately 180 m long and 20 m wide. The street canyon has an aspect ratio approximately equal to one (H/W=1) and has a roughly N-S orientation.

At Belleville, watering was limited to the cobblestone pavement only. The watered portion was located on rue Lesage while the dry portion was on rue Ramponeau, a parallel street nearby. The watered portion was approximately 40 m long and 4 m wide. Both canyons have an aspect ratio approximately equal to one and have a roughly E-W orientation.

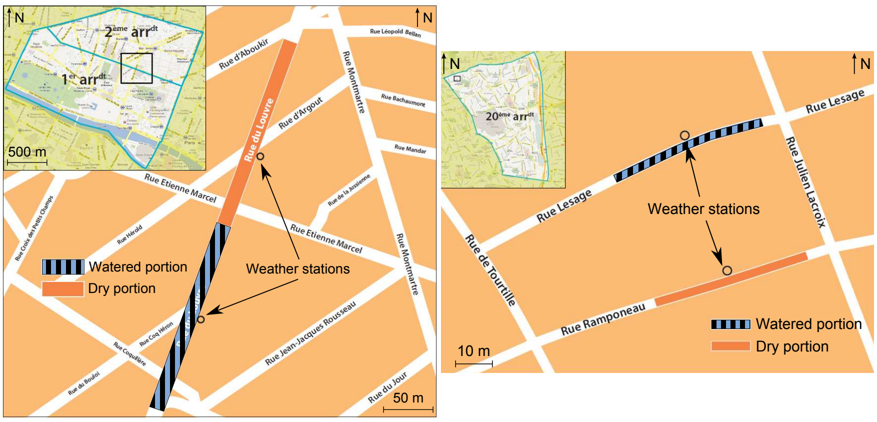

Figure 1: Map of weather station positions at the Louvre (left) and Belleville (right) test sites.

Instruments

Weather station design is presented in Figure 2. Instruments within pedestrian reach were protected behind a 2-m cylindrical white-painted steel cage. All parameters were recorded every minute and smoothed with a one-hour moving average. The final series was obtained by keeping four data points per hour from the smoothed series. All data is presented in local daylight savings time (UTC +2). Table 1 lists the instruments used for this analysis as well as their height and accuracy.

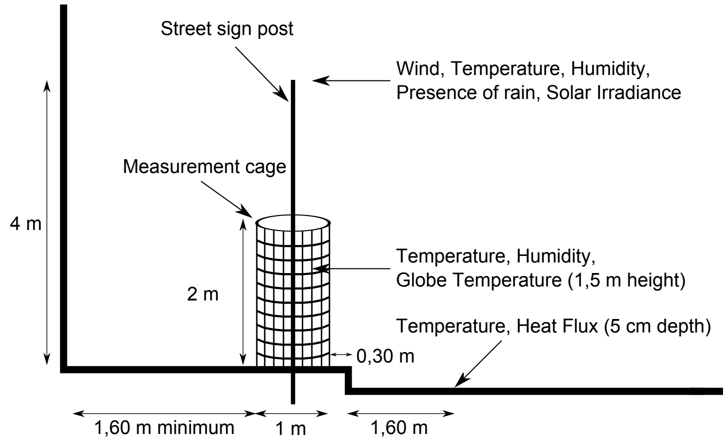

Figure 2: Weather station design and instrumentation. The temperature and heat flux sensor was only installed at the Louvre site.

Table 1: Instrument type, measurement height and accuracy

Parameter	Instrument	Height	Accuracy
Air temperature	Sheltered Pt100 1/3 DIN B	1.5 m	0.1°C
Relative humidity	Sheltered capacitive hygrometer	1.5 m	1.5% RH
Black globe temperature	Pt100 1/2 DIN A - ISO 7726	1.5 m	0.15°C
Wind speed	2D ultrasonic anemometer	4 m	2%

Thermal comfort evaluation

The effects of pavement-watering were quantified by MRT and UTCI.

Since we are studying the potential for pavement-watering to reduce the health impacts of intense heat-waves, one of the indexes should be able to properly assess heat-related health impacts. Thorsson et al. (2014) found that MRT was a better predictor for heat-related mortality than air temperature, which is more commonly used. MRT was therefore chosen for these reasons.

However, although it may be effective at predicting heat-related mortality, MRT is a relatively new index for heat stress and does not currently allow us to evaluate intermediate levels of heat stress. Furthermore, it ignores the effects of wind speed, air temperature or humidity on thermal comfort. We therefore need to include an index that takes all relevant climatic aspects into account.

One of the more recently developed thermal comfort indexes is the Universal Thermal Climate Index (UTCI) (Blazejczyk et al., 2010). UTCI was developed by international experts from Commission 6 of the International Society of Biometeorology (ISB) and European COST Action 730 from the year 2000 to 2009. It is based on a special version of the multi-node Fiala thermophysiological model. Air temperature, humidity, wind speed and MRT are used as well as assumptions on the metabolic activity and clothing of pedestrians to calculate an equivalent air temperature for reference conditions.

To calculate MRT, black globe temperature (T_g), air temperature (T_a) and wind speed (v) measurements from the weather station were used according to the method described by ASHRAE (2001). Air temperature, relative humidity, MRT and wind speed measurements were then used to obtain UTCI equivalent temperature, which was fast-calculated with the FORTRAN code written by Peter Bröde in 2009, adapted for use with the R software environment. The source code is freely available at http://www.utci.org/utci_doku.php.

Inaccuracies are introduced into both MRT and UTCI by the use of 4-m wind speed rather than 1.5-m and 10-m wind speed, respectively, as well by globe temperature measured inside the cylindrical cage.

Watering method

Watering was started if certain weather conditions were met based on Météo-France's three-day forecast. These as well as those for heat-wave warnings in Paris are presented in Table 2. BMI_{Max} and BMI_{Min} refer to the 3-day mean of maximum (T_x) and minimum (T_n) air temperature.

At the Louvre site, cleaning trucks were used to sprinkle sidewalk and pavement every hour in the morning (6:30 am to 11:30 am) and every 30 minutes in the afternoon (2 pm to 6:30 pm). At the Belleville site, a removable 40-m watering pipe was laid along the gutter to water the pavement on rue Lesage continuously from 7 am to 7 pm. In terms of the watered surface ratio, rue du Louvre was 100% watered, while rue Lesage was approximately 33% watered. Water used for this experiment was supplied by the city's 1,600-km non-potable water network, principally sourced from the Ourcq Canal.

Table 2: Weather conditions required for pavement-watering and heat-wave warnings

Parameter	Pavement-watering	Heat-wave warning level
BMI_{Min}	≥ 16°C	≥ 21°C
BMI_{Max}	≥ 25°C	≥ 31°C
Wind speed	≤ 10 km/h	-
Sky conditions	Sunny (less than 2 oktas cloud cover)	-

Data selection and interpretation method

Because many weather conditions were encountered over the duration of the experiment, only days of Pasquill atmospheric stability class A-B or more were retained for the upcoming analyses (Pasquill, 1961). This provision limits selected days to those with clear skies (less than 3 oktas) and low wind speeds (less than 3 m/s).

To interpret the effect of pavement-watering on MRT or UTCI, the difference between the watered and control stations is analysed, calculated as: $y_{difference}=y_{watered}-y_{control}$. Negative values indicate that the watered station parameter is lower than that of the control station, and vice versa.

However, even with these provisions in mind, it is not possible to determine the effect of pavement-watering by analyzing the raw data from the weather stations. To eliminate the high natural variability in the data, a statistical representation of the daily profile of the difference is used instead, calculated for dry (control) days and case (watered) days.

Finally, because no watering occurs between midnight and 6 am, days will be divided into 24-hour periods beginning at 6 am and ending at 5:59 am the next day. Thus, when we refer to data from July 8th for example, this means from July 8th at 6 am to July 9th at 5:59 am.

RESULTS

Weather stations recorded continuously from July 2nd until September 10th, 2013. Over this period, ten days met the conditions set for pavement-watering. Of the ten watered days, July 8th, 9th, 10th and 16th were the coolest (T_x≤30°C), with July 22nd, 23rd, August 1st and 2nd being the warmest (T_x≥35°C, T_n≥20°C). August 23rd and September 5th were also watered and had intermediate temperatures (35°C≥T_x≥30°C).

Several measurement interruptions occurred over this period. Rue du Louvre was most affected with its control station unoperational from July 19th until August 19th and from September 4th until September 10th. At Belleville, only one interruption occurred from the 22nd to the 25th of July. These events were poorly timed, resulting in the absence of control measurements on July 22nd and 23rd at either site and on August 1st and 2nd at the Louvre site.

It should therefore be kept in mind that results from rue du Louvre only include the coldest watered days, while July 22nd and 23rd are missing from the Belleville data.

Effects on mean radiant temperature

Figure 3 illustrates the difference between watered and control stations at the Louvre (top) and Belleville (bottom) sites for MRT. Deviations between the blue and red curves are statistically significant only if the blue curve is not between the dotted red lines.

As can be seen, both sites behave quite differently, with signal amplitudes ranging from [-2°C;4°C] at the Louvre site to [-6°C;10°C] at the Belleville site. 24-hour mean and maximum cooling effects are summarized in Table 3.

24-hour average and daily maximum effects are quite different between sites. Although a net cooling effect of 0.36°C is seen at the Louvre site, a warming of 0.09°C is seen at Belleville. However, the latter result is not statistically significant. No statistically significant 24-hour effect is therefore detected for Belleville, while a staticsally significant average cooling of 0.36°C is seen for Louvre.

When the hourly curves in Figure 3 are considered, the MRT difference curve is always lower on watered days than on dry days at the Louvre site. This is not the case at the Belleville site. However, the deviations between the control and watered day curves are not always statistically significant at either site. Overall, the effects are most often statistically significant at night and at the Louvre site. The maximum effects reported in Table 3 are statistically significant at both sites.

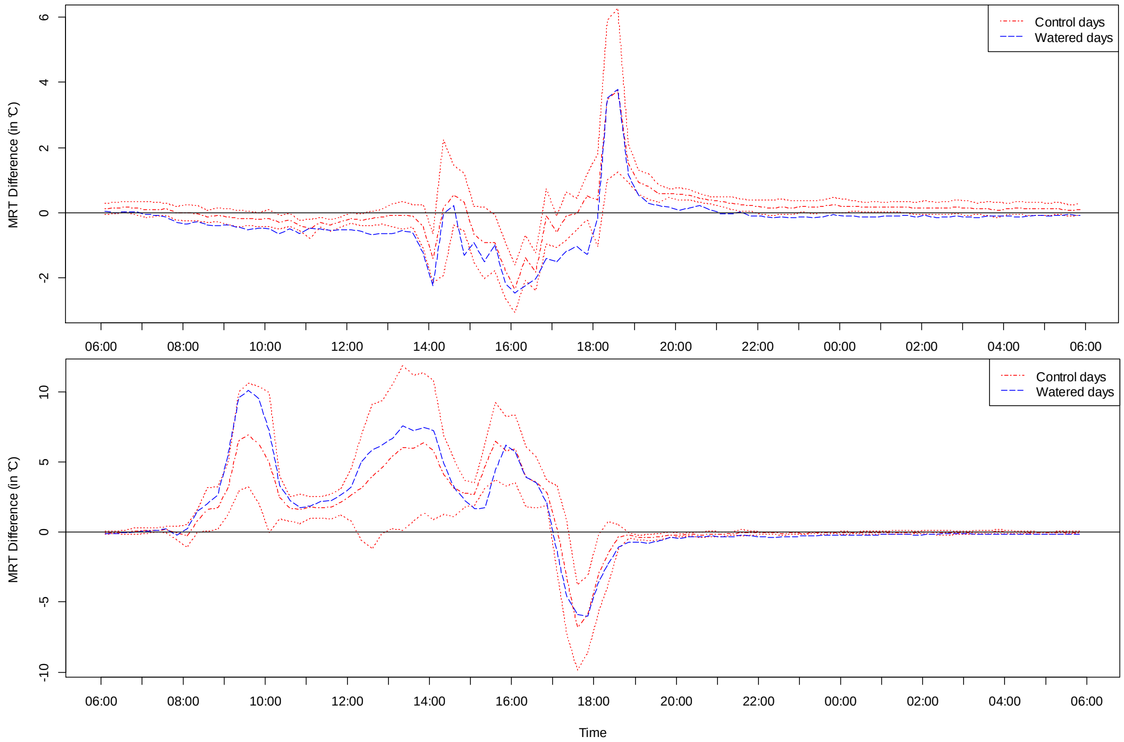

Figure 3: Difference in mean radiant temperature between twin stations at the Louvre (top) and Belleville (bottom) sites. Solid lines indicate the mean value for control (red) and watered (blue) days, dotted red lines indicate the 95% confidence interval of the difference between the control and watered day mean curves.

Table 3: Mean and maximum cooling effects of pavement-watering on MRT at Louvre or Belleville

Site	Mean (24-hour) effect	Maximum effect
Louvre	0.36°C	1.79°C
Belleville	-0.09°C	2.94°C

Effects on pedestrian thermal comfort

Figure 4 illustrates the hourly difference between watered and control stations at the Louvre (top) and Belleville (bottom) sites for UTCI.

As was the case for MRT, both sites behave quite differently, despite reduced signal amplitudes compared to that of MRT with [-0.5°C;1.75°C] at Louvre and [-2°C;3.5°C] at Belleville. 24-hour mean and maximum cooling effects are summarized in Table 4.

Unlike for MRT, the effects on UTCI are relatively similar between sites. UTCI is reduced by an average of 0.21°C at the Louvre site and by 0.12°C at the Belleville site. However, only the effect on rue du Louvre is statistically significant. No statistically significant 24-hour effect on UTCI is therefore visible at the Belleville site.

When the hourly curves in Figure 4 are considered, statistically significant effects exist, although they are less numerous than for MRT. Maximum effects are significant and in the same order of magnitude, between 0.98°C and 1.20°C. As was the case for MRT, the hourly effects are most often significant at night and at the Louvre site.

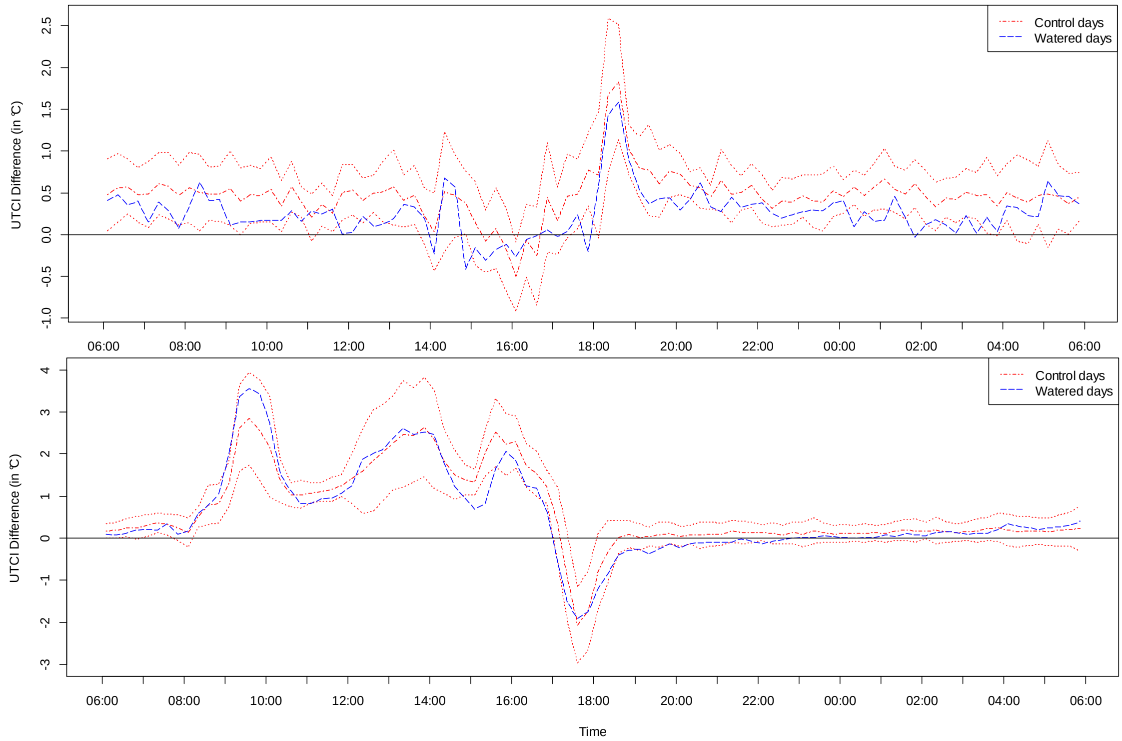

Figure 4: Difference in UTCI between twin stations at the Louvre site (top) and at the Belleville site (bottom). The dashed lines indicate the mean value for control (short red dashes) and watered (long blue dashes) days, while red dotted lines indicate the 95% confidence interval of the difference between the control and watered day mean curves.

Table 4: Mean and maximum cooling effects of pavement-watering on UTCI at Louvre or Belleville

Site	Mean (24-hour) effect	Maximum effect
Louvre	0.21°C	0.98°C
Belleville	0.12°C	1.20°C

DISCUSSION

For both MRT and UTCI, 24-hour average effects are always greater at the Louvre site, while maximum effects are higher at the Belleville site. Furthermore, the 24-hour average effects site are only statistically significant at the Louvre site, while maximum effects are always significant regardless of the site considered. Finally, the hourly effects are most often significant at night and at the Louvre site. Maximum effects for MRT were in the order of a few degrees Centigrade while they were around one degree for UTCI. Overall, greater, more significant results were found for MRT than for UTCI.

On the one hand, the more significant and higher 24-hour results obtained at rue du Louvre are most likely explained by the proportion of street that is watered. While rue du Louvre was watered over 100% of its width, only a third of rue Lesage was watered.

On the other hand, the highest maximum effects were reached at the Belleville site. This may be linked to the absence of data on the hottest watered days for the Louvre site, when the effects are expected to be highest. However, it could also be linked to the Belleville site's orientation, since both site canyons have the same aspect ratio. For an aspect ratio of one, N-S streets experience similar conditions on either side of the street, while E-W streets have very different conditions between the North and South sidewalks, due to predominant daytime sunlight or shade, respectively. Maximum heat stress conditions are therefore much higher on the North side of an E-W street than on its South side or in a N-S street during the summer. These links between aspect ratio, orientation and pedestrian thermal comfort were studied by Ali-Toudert & Mayer (2006). Since it is expected that the effects are greatest in the hottest conditions, cooling may be increased by watering the North sidewalk rather than the pavement on rue Lesage. However, because of the missing data at the Louvre site, this cannot be confirmed. Finally, the difference in paving materials may also explain some of these aspects.

We now look to evaluate the health or comfort impacts of these effects. No universal relation with mortality risk has been established for MRT at this time to our knowledge, while UTCI is scaled according to five heat stress levels for hot environments. To evaluate the effect of pavement-watering on pedestrian thermal comfort through UTCI, we must therefore compare the effect with the span of the UTCI heat stress categories, i.e. between 6° and 8°C. With a maximum cooling effect of 1.2°C, pavement-watering has a limited effect on pedestrian thermal comfort, only rarely causing a downwards shift in heat stress category. However, it should be noted that pavement-watering performs well in comparison to other urban surface cooling methods, such as high-albedo pavement materials (Erell, Pearlmutter, Boneh, & Kutiel, 2013).

CONCLUSIONS

The effects of pavement-watering on pedestrian thermal comfort were evaluated via MRT and UTCI, using data collected during a field experiment of pavement-watering conducted at two sites in Paris, France over the summer of 2013. The N-S site was entirely watered, while only the pavement, corresponding to a third of total width, of the E-W site was watered.

For both MRT and UTCI, average cooling effects were highest at the N-S site, reaching 0.36°C for MRT and 0.21°C for UTCI, while maximum cooling was highest at the E-W site, with up to 2.9°C for MRT and 1.2°C for UTCI. Average cooling at the E-W site was not statistically significant, while maximum cooling was significant at both sites.

The higher effect reached at the Belleville site may be closely tied to the street's orientation, but further measurements would be necessary to confirm this. If this is the case, it may be more efficient to water the North sidewalk of E-W streets rather than their pavement.

To our knowledge, no tools currently exist to evaluate the health impact of observed MRT cooling. It is therefore not yet possible to estimate the health impacts of pavement-watering with MRT. In terms of UTCI, observed cooling was found to be limited in comparison to the level necessary to obtain a downwards shift in heat stress category. Regardless, the method performs better than others such as high-albedo pavement materials.

In order to continue to evaluate pavement-watering against other methods such as urban greening or artificial shading, further studies such as that conducted by Shashua-Bar, Pearlmutter, & Erell (2011) should be conducted in the Parisian urban environment. Trials should take all relevant decision-making factors into account, including the cost, water consumption and feasibility of each method.

NOMENCLATURE

BMI	=	biometeorological index [°C]
MRT	=	mean radiant temperature [°C]
T_n	=	minimum daily temperature [°C]
T_x	=	maximum daily temperature [°C]
UTCI	=	universal thermal climate index [°C]

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Sunlight Availability for Food and Energy Harvesting in Tropical Generic Residential Districts

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ABSTRACT

Increasing food and energy self-sufficiency in residential areas is one of the key measures to reduce greenhouse gases emissions as well as to mitigate and adapt to climate change. The objective of the study is to verify the impact of building typologies and urban forms with relative high density on sunlight availability. Computational tools are employed to obtain quantifiable indicators of the potential of each variant for energy and food harvesting.

Three typical residential typologies, namely, point block, slab block, and contemporary block, in Singapore were identified. Point block typology was assessed in this paper. Twenty five point block cases were assessed in terms of solar access by using three density and geometry parameters: plot ratio, site coverage and building height. Each case was considered on a plot of 520x520m2. Singapore's weather and sky conditions (1.3°N) were used for the analysis.

Out of the 25 cases, six with the lowest plot ratio between 0.8 and 1.9 achieved food self-sufficiency when a hybrid (conventional and vertical) farming method was applied. The cases with the lowest building height (<42 m, <14 storeys) achieve energy self-sufficiency due to the maximum exposed area with PV per amount of residents. The indicators having the higher impact on the food and energy self-sufficiency were plot ratio and building height respectively. The study provided the basis for future environmental and energy assessments including the potential of each variant for natural ventilation and carbon footprint reduction.

INTRODUCTION

The rapid urbanisation process occurring along the tropical belt promotes the construction of new residential districts, especially in south-east Asia (SEA) countries. In Singapore, the construction of new dwellings is an important part of the building sector. The need to build higher density residential districts to accommodate the growing population in the land-scarce Estate-Island oblige the demolition of relatively old housing estates and build new ones. The land occupied for building new residential districts is, most of the time, located in the peri-urban area in which agricultural activities are foremost. There is a twofold negative effect: increasing food demand by growing population and decreasing farming areas around the cities by the construction of new residential districts. This situation increases the food dependence of Singapore from neighbouring countries. Therefore, increasing local self-sufficiency in terms of food and energy in residential areas is one of the key measures to reduce greenhouse gases emissions as well as to mitigate and adapt to climate change.

Urban farming has proved to considerably reduce the food supply chain as well as to socially and

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economically benefit the local population. In addition, the installation of solar panels (photovoltaic and solar collectors) on building envelopes will be the norm if the current trend of more efficient and less expensive panels is prolonged. Therefore, the integration of farming areas and the potential installation of solar panels should be considered as some of the design parameters for new residential districts in Singapore and SEA.

Numerous studies have tackled the problem of the insertion of productive gardens in urban areas from the point of view of land use planning (Indraprahasta, 2012), of the use of roof top (Astee & Kishnani, 2010) and of vertical farming and high-tech methods (Despommier, 2013). In addition, several studies have been conducted on the potential of the urban form to harvest solar energy (Kanters & Horvat, 2012) and on the calculation methods of solar distribution on urban environments and solar access (Ibarra & Reinhart, 2011). In the context of Singapore, several studies have dealt with the impact of urban form on several environmental indicators like daylight and natural ventilation (Zhang el al. 2012; Lee et al. 2013)

However, no study was found in literature about the impact of urban form on sunlight availability for food production. There is also a need to conduct a comprehensive study dealing with both food and energy harvesting in tropical high density areas. Therefore, the objective of this study is to verify, through the use of computational tools, the impact of a series of densities and urban forms on sunlight availability for one of the three identified typical public housing typologies in Singapore: point block. This is translated into coefficients of self-sufficiency in terms of food (vegetables and fruits) and energy. The study provides the basis for future environmental and energy assessments including the potential of each variant for natural ventilation and carbon footprint reduction.

METHOD

The study is divided into three main stages: (1) calculation of solar availability on the point-block cases, (2) calculation of the potential of food harvesting on ground and facades and, (3) calculation of the potential of energy harvesting by Photovoltaic (PV) panels on facade and roof surfaces.

Building typology and simulation cases

Three typical public housing typologies from Singapore (Housing Development Board (HDB)) and, to some extent, from other SEA new urban areas will be assessed: point block, slab block and contemporary block. However, in this paper only the analysis of the point block typology is presented. **Table 1 shows** a summary of the twenty five point block cases that are assessed in terms of solar access by using density and geometry parameters: plot ratio (PR), site coverage (C_s) and building height (H_b). PR is defined as the ratio of the gross floor area of all buildings to the area of the analysed plot where all buildings are located. C_s is defined as the ratio of the ground floor area of all buildings to the area of the analysed plot. H_b may vary from case to case but all buildings in the same case has equal H_b.

The plot area is the same for every case: 520 x 520m^2 (27 ha). This represents the equivalent area of a typical large precinct in Singapore or several small ones including the area for car circulation. A similar plot area was used in a natural ventilation study for typical residential district in Singapore (Lee et al. 2013). **Figure 1 shows** the different C_s and building arrangements for the point-block typology. The different densities were defined departing from the typical PR of the most recent HDB developments in Singapore (PR = 3.0). Then a matrix was developed considering PR, C_s and building height. The height varies in order to keep the same -or very similar- PR on the cases coinciding with the diagonal of the matrix **as shown in Figure 1.** That means a case (2-4) having site coverage 13% with 27 floors has the same PR = 3.0 than a case (4-2) with C_s of 21% and 17 floors. For the sunlight availability simulations, every case is partially replicated in order to take into account the effect of neighbouring buildings. **Figure 2 shows** the extended models for three C_s: 10%, 16% and 27%.

Singapore's weather conditions (1.3°N) are considered for the analysis. The sky conditions are considered as intermediate sky which is typical for Singapore along the year. However, the actual values of solar radiation are taken into account from the ASHRAE International Weather for Energy Calculations (IWEC) Data (US Department of Energy, 2013). The sunlight availability of three cases is contrasted with the conditions of Hanoi, Vietnam (21°N) to assess the influence of latitude.

Table 1. Summary of 25 cases and building indicators corresponding to Point Block typology.

Cases	Nr floors	Nr Buildings	Site coverage (Cs)	Plot Ratio (PR)
1-1 to 1-5	10 to 36	36	10%	0.8 to 3.0
2-1 to 2-5	12 to 32	48	13%	1.3 to 3.6
3-1 to 3-5	14 to 30	60	16%	1.9 to 4.2
4-1 to 4-5	14 to 28	76	21%	2.5 to 4.9
5-1 to 5-5	13 to 25	100	27%	3.0 to 5.8

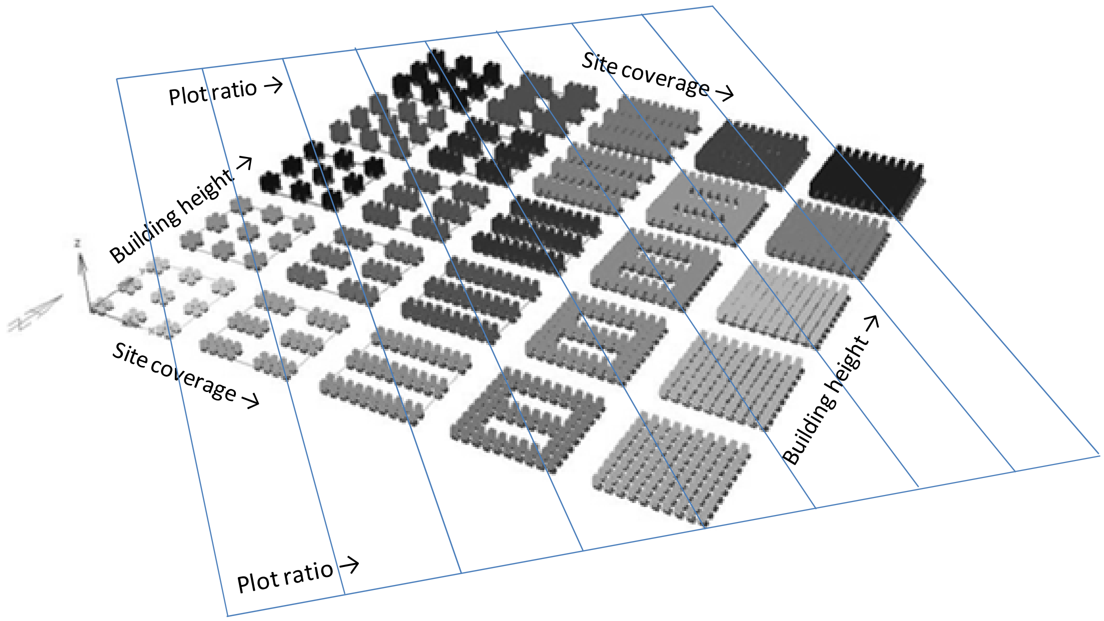

Figure 1 Schematic of the 25 cases corresponding to the point block. The analysed cases are organized according to a matrix of site coverage (X-axis), building height (Y-axis) and plot ratio (diagonal). Case 1-1 is at bottom left, case 1-5 is at top left and case 5-5 is at top right.

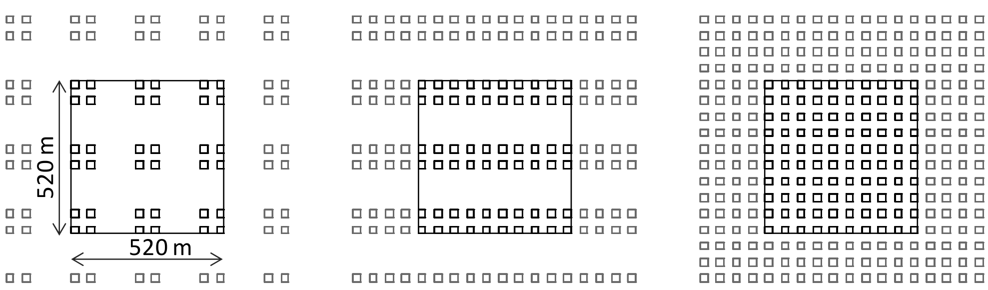

Figure 2 Schematic of the simulation model for three of the 5 different building dispositions according to site coverage of 10%, 16% and 27%. The framed area is the analysed area.

Settings and calculation method

Sunlight availability. The software Daysim (version 3.1b) (Reinhart and Walkenhorst, 2001) was used to perform the calculations of the solar availability (illuminance levels) on the ground, facade and roof surfaces. Daysim is a Radiance-based program (Ward and Shakespeare, 1998) able to simulate time series of solar irradiances and illuminance levels. This version of Daysim can be integrated into Autodesk Ecotect which facilitates the modelling of the geometries while allows more accurate calculations in comparison with the Ecotect Solar access model (Ibarra & Reinhart, 2011).

Radiance simulation parameters were defined according to 'scene complexity 1'. This means 5 ambient bounces, 1000 ambient divisions and 300 ambient accuracy among other parameters. The simulation accuracy is increased by using the DDS model which more precisely accounts for the effect of obstructions (neighbouring buildings) on the incident radiation and illuminance values.

Daysim calculates both the Daylight Autonomy (DA) and the average illuminance levels per point for the analysed period (whole year). The DA is a climatic-based index which denotes the percentage in which a minimum –defined by user- illuminance level is achieved by daylight alone for a specific time interval (Reinhart and Walkenhorst, 2001). In this study, DA is used to determine the percentage along the whole year in which each analysed point receive more than 10 000 lux from 8:00 till 18:00. The optimal illuminance level for certain vegetables and fruits is considered to be 10 000 lux for about 8 hours (Conover and Flohr, 1996). When the DA is below 80% (less than 8 hours with 10 000 lux), a reduction coefficient is applied for the calculation of the annual yield.

A grid of points (lighting sensors) was generated in every case to obtain the illuminance levels. For the ground a grid of 5 m by 5 m was generated among the buildings. For the facades grids of 5 m (X or Y axes according to orientation) by 12 m (Z axis) were generated adapted to the building height. In the case of the roof, a single point was defined due to the lack of obstructions from other buildings. No distinction is made about the different solar availability per facade orientation and height. The average of all facade points will be considered for the calculation of both the farming and solar energy potential.

The effect of shading devices (30 cm overhang along all facades on every floor) on ground and facade illuminance levels (lux) is considerable: 4% lees sunlight on ground surface and 12% less on facades. However, modelling all shading devices increase the calculation time several times, therefore, an equivalent reflectance coefficient (-20%) on the facade was applied to account for the ground illuminance reduction due to the shading devices. But since the facade reflectance values have little impact on the facade illuminance levels, another coefficient is applied directly on the final illuminance levels to account for the presence of horizontal shading devices. For overhangs of 30cm, a coefficient of 0.9 will be applied accounting for a 10% reduction.

Population and area for farming and PV panels. The amount of population per case is calculated considering that 70% of GFA is residential, 20% institutions and 10% commercial. The total amount of residents per case were calculated according to the average area per capita in the HDB of the last decade equal to 25m^2 and considering a floor plan efficiency (rental flat area out of GFA of residential building) equal to 85%. For the farming activity we consider part of the ground area and part of the facade while for the solar energy harvesting we consider part of the roof surface and part of the facade. The farming area on the ground was derived from the actual land use at Punggol New Town in the northeast of Singapore. From the total plot area, 15% is considered to be for roads and 35% for open space and recreation. The 50% remaining area is distributed between buildings and farming areas according to the different C_s. The area for car parks is considered to be underground or above ground. In the latter case, the roof of the car park is considered to be covered by playgrounds, circulation, green and farming areas. The farming area on the facade considers 50 cm of planters along 30% of the perimeter of the facade. Three fifths of the planter's thickness (30cm) is projected outside of the building facade acting as a shading device. The remaining is considered to be inside the facade perimeter as part of a balcony or external common corridor. The other 70% of the facade perimeter is considered to be used for the installation of Building Integrated Photovoltaic (BIPV) panels. Eighty percent of the roof area is considered to be covered by solar panels.

Selection of crops and food self-sufficiency. A selection of crops was done in order to calculate the yield potential of the farming areas and the potential of food (vegetables and fruits) self-sufficiency of the total population in each case. The criteria to select the type of crops were (1) suitability for local context, (2) preference among local residents and, (3) productivity. A reduced variety of vegetables and fruits were chosen with different productivity indices. The vegetables are Kang Kong (30%), Water Mimosa (20%), Chinese Celery (20%), Water Cress (10%) and Pumpkin (20%); the fruits are Dragon Fruit (80%) and Banana (20%). The yield from the crops ranges from 5 to 30 tonnes per hectare for the Pumpkin and the Dragon Fruit respectively. The food cycle per year is from 1 to 18 for Banana and Kang Kong respectively.

Two scenarios are considered regarding the technology used for farming. The first one, termed as 'conventional', refers to urban ground farming methods. This method considers both the traditional ground soil gardening and the use of soil planters or containers. The second scenario is termed as 'hybrid' and it is a combination of the 'conventional' and the 'vertical' methods (50% ground surface each). The 'vertical' method refers to hydroponics, aeroponics and vertical soil-based structures like the A-shaped SkyGreen system introduced in Singapore. The vertical methods are considered to be around 4 times more productive than the conventional ones (Mugundhan, 2011). Only vegetables are considered to grow using the 'vertical' method. **Table 2 shows** the area needed for vegetables and fruits in order to achieve self-sufficiency per capita for the two scenarios.

Table 2. Area needed in order to achieve food self-sufficiency per capita (2 scenarios)

	Yield needed per year per capita (t)	Area needed per year per capita (conventional) (m^2)	Area needed per year per capita (hybrid) (m^2)
Vegetables	109	9.4	3.7
Fruits	55	14.8	14.8
Total	164	24.2	18.5

PV panels and energy self-sufficiency. Polycrystalline Silicon (pc-Si) and Thin-film Amorphous Silicon Copper Indium Selenide (a-Si CIS) on a horizontal position were considered for the roof and facade respectively. Typical efficiencies and temperature factors were considered: 13% and 8% for pc-Si and a-Si CIS respectively. The energy use per capita of 1287 kWh from April 2013 till March 2014 is considered for the calculation of energy self-sufficiency corresponding to a typical HDB apartment (Singapore Power Group, 2014). Solar collectors for water heating are not considered at this stage.

RESULTS

The results corresponding to the solar availability analysis and the potential of food and energy harvesting for 25 cases of point block typology are presented in this paper.

Sunlight availability

The results of the illuminance levels (luxh) per point are averaged for the ground and facade respectively. **Figure 3a shows** the average illuminance levels for the 25 cases on ground and facade points. As expected, when density (PR) increases, sunlight availability (illuminance levels) decreases. The decrease of illuminance levels is less evident on the facade points (15%) than on the ground (45%) because all facades, disregarding its orientation and the plot density, have a limited (≤ 0.5) sky view factor in comparison with less obstructed horizontal surfaces (≤ 1.0). **Figure 3b shows** the average percentage of time in which illuminance levels are above 10 000 lux. Here the differences between the lowest and highest densities are lower both for the ground points (around 12%) and facade points (6%).

Farming potential and food self-sufficiency

Figure 4a shows the ratio of food self-sufficiency for the conventional and hybrid cultivation methods. The differences between the two methods are more evident on lower densities in which larger ground area is available for the installation of the vertical farming systems.

The impact of the different urban density indicators was analysed. The H_b alone has a minor influence on the ratio of self-sufficiency (R^2=0.2). The increase of H_b results on a counterbalance effect: first it allows larger building facades with a higher potential for the installation of planters, but it also means a larger amount of residents. The second factor is more influential and make that, in general, the higher the building the less potential for self-sufficiency. C_s has a higher impact on food self-sufficiency because the amount of land available for farming is directly proportional to C_s. Therefore, there is a stronger correlation between food self-sufficiency and C_s (R^2=0.65). PR, **shown in Figure 4b,** and population density have the strongest correlation: R^2=0.96 and R^2=0.95 respectively. This is expected because the building and population density take into account both the horizontal (C_s) and vertical (H_b) densities factors.

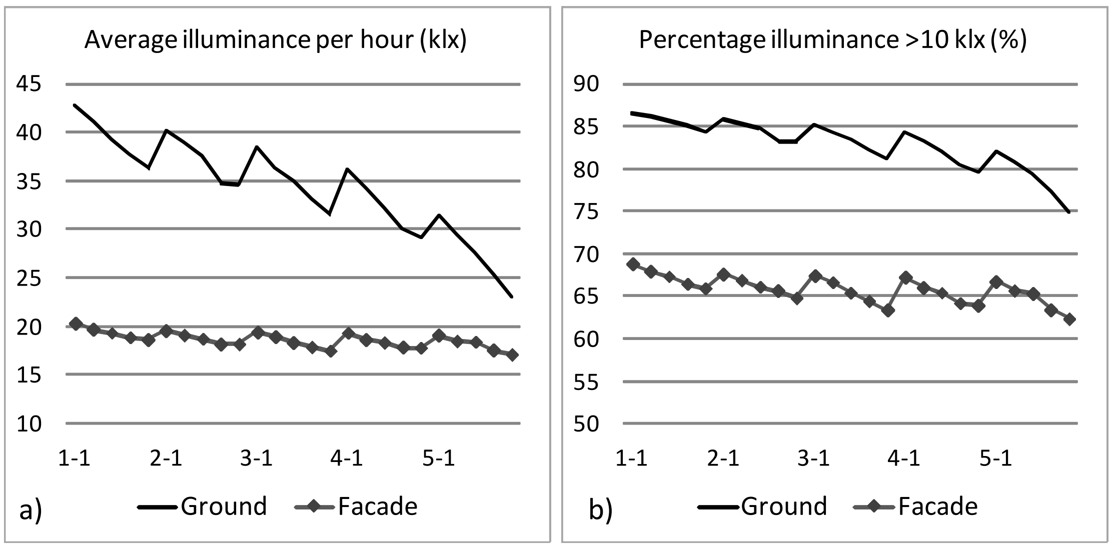

Figure 3 (a) Average illuminance levels per hour for the ground and facade points and (b) average percentage of time in which illuminance levels are higher than 10 000 lux.

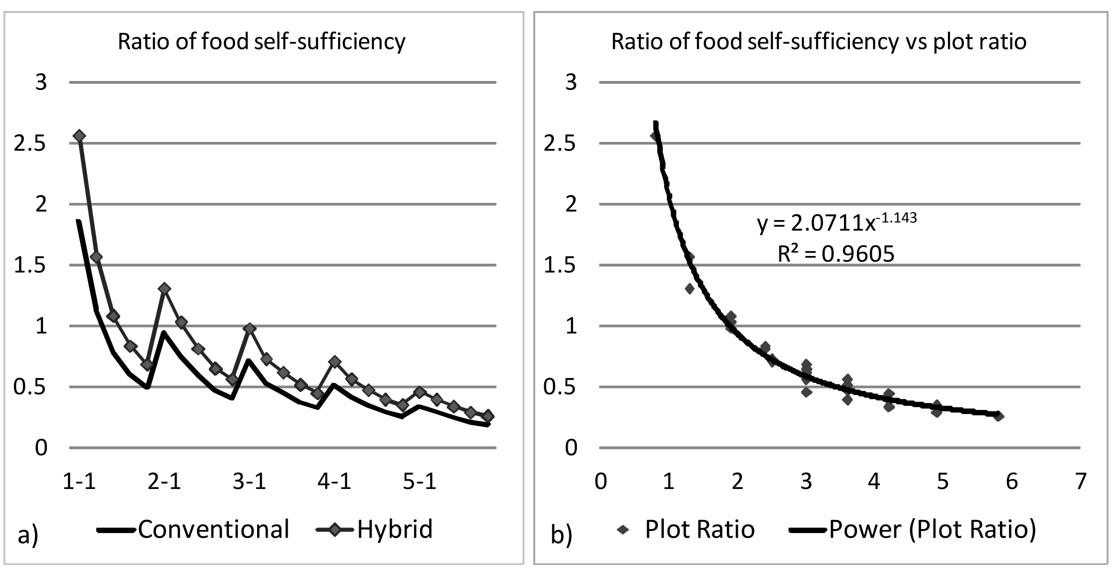

Figure 4 (a) Ratio of food self-sufficiency for the conventional and hybrid cultivation methods (ratio ≥ 1 self-sufficient) and (b) Correlation of the ratio of food self-sufficiency to plot ratio.

Solar energy potential and energy self-sufficiency

Based on the assumption of having 80% of the roof surface covered by PV panels and by considering BIPV as shading devices (30cm) on 70% of the facade perimeter on each floor the following results **shown in Figure 5** were obtained in terms of energy self-sufficiency. As expected, the highest energy output was obtained on the densest case (5-5 with PR = 5.8) due to the larger total roof surface and facade perimeter (more and higher buildings). However, when calculating the energy output relative to the amount of residents the cases with the lowest H_b (<42 m, cases 1-1, 2-1, 3-1, 4-1 and 5-1) are the only ones achieving energy self-sufficiency (> 98%) **as shown in Figure 5a**. This is also evident **in Figure 5b** which shows a strong negative correlation (R^2=0.98) between energy self-sufficiency and H_b. The taller the building the lower the energy self-sufficiency due to the fact that the increase of PV panels does not counteract the effect of the larger amount of population on energy demand. Different from food self-sufficiency, PR has a much lower correlation with the energy self-sufficiency (R^2=0.43). This may be explained by the fact that even with the same plot ratio, two cases may have different roof area for PV panels. I.e. cases 1-5 and 5-1 (PR = 3) have 37% and 77% of energy self-sufficiency respectively.

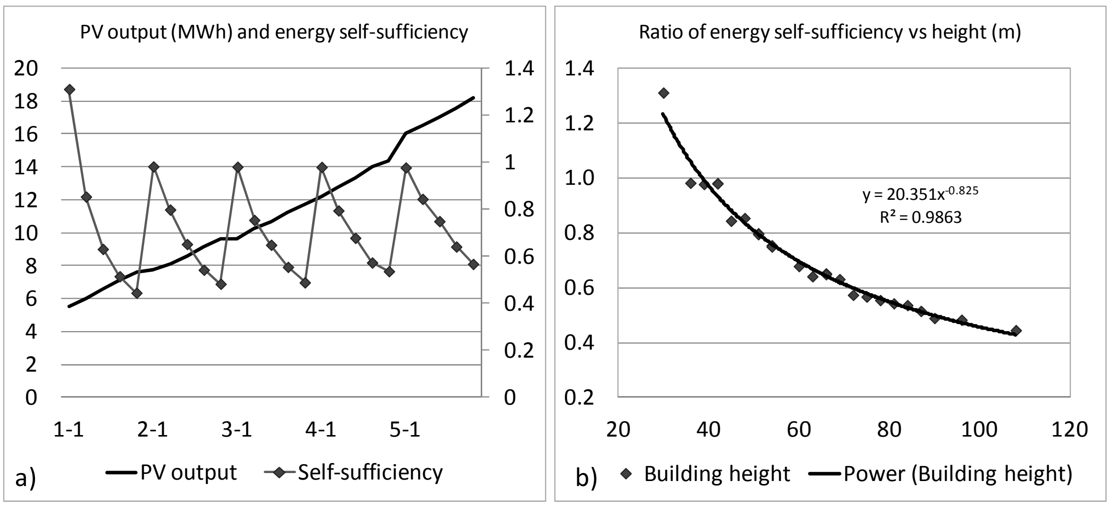

Figure 5 (a) Energy output from PV panels (roof + facade) and energy self-sufficiency and (b) correlation of the ratio of energy self-sufficiency to building height.

Sunlight availability on higher latitudes

A comparison was made between Singapore and Hanoi in terms of DA (%) **as shown in Table 3.** The reduction of the DA in Hanoi is significant for the ground if PR is higher than 3. For the facade sunlight availability, this reduction is significant for all PR. Therefore, the impact of higher densities on the reduction of sunlight for farming and energy harvesting becomes larger with higher latitudes.

Table 3. Comparison between Singapore and Hanoi, DA (%)

		DA [%] Ground average		Ratio [-]	DA [%] Facade average		Ratio [-]
Cases	**Plot Ratio**	**Singapore**	**Hanoi**	**Hanoi / Sing**	**Singapore**	**Hanoi**	**Hanoi / Sing**
1-1	0.8	87	81	**0.93**	73	52	**0.71**
3-3	3	83	73	**0.88**	70	46	**0.66**
5-5	5.7	75	55	**0.73**	66	42	**0.64**

CONCLUSION

This paper describes the process and results of the first stage of a study on solar availability on three typical public housing typologies. Twenty five cases corresponding to the point block typology were analysed in this paper. Sunlight availability was calculated in order to predict the potential of food (fruits and vegetables) and energy harvesting and the degree of self-sufficiency on each of the 25 cases. Ground and facade surfaces were considered for the farming activities while facade and roof surfaces were considered for the installation of PV panels. The results show that food self-sufficiency is achieved in 6 of the 25 cases corresponding to the cases with the lowest PR (0.8 ≤ PR ≤ 1.9) if a hybrid farming method is applied (conventional + vertical). If conventional method of ground-based farming is used, only two cases achieve self-sufficiency. Regarding energy harvesting, the cases with the lowest building height (< 42 m, < 14 storeys) achieve energy self-sufficiency due to the maximum exposed area with PV per amount of residents. Therefore, the indicators having the highest impact on the food and energy self-sufficiency are the plot ratio and building height respectively. However, this may not be fully applicable on other typologies and urban forms. Site coverage is still a crucial factor in providing food autonomy in urban areas due to the higher importance of ground than facade surfaces for the total food production.

From this study we can conclude that in tropical regions the reduction of food and energy self-sufficiency due to denser urban environments is more a consequence of the reduction of the farming and PV area in relation to the total population than to the reduction of the sunlight availability. However, as shown in the case of Hanoi, with higher latitudes and a lower frequency of the sun near the zenith, the impact of the surrounding obstructions on reducing the sunlight availability increases.

The other two typical housing typologies in Singapore, 'slab' and 'contemporary', will be the continuation of this study. In addition, the influence of the facade and plot orientations and of the sunlight availability at different facade heights will also be analysed together with the integration of other types of energy harvesting and conservation technologies like solar thermal and algae bioreactors. These studies will provide the basis for further environmental and energy assessments as well as a framework for a more comprehensive discussion about the impact of food and energy self-sufficiency strategies on several urban indicators in pursuit of a drastic carbon footprint reduction.

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The Cooling Effect of Green Strategies Proposed in the Hanoi Master Plan for Mitigation of Urban Heat Island

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ABSTRACT

This study aims to assess the impacts of land use changes brought by the Hanoi Master Plan on its urban climate using the Weather Research and Forecasting (WRF), focusing on the cooling effect of the green strategies that were proposed in the master plan. The results show that even after implementing the master plan, the peak air temperature in the urban areas still remains at the same level of 41°C. However, the expansion of built-up areas largely increases the UHI intensity and raises the nocturnal air temperatures in the built-up areas. The centralized green spaces proposed in the master plan is seen to be insufficient to mitigate UHIs compared to the equally distributed green spaces. The urban air temperature in Hanoi is increased when the westerly or south-westerly Foehn winds flow over the city during the daytime. In contrast, relatively strong and cool southerly winds prevail during the night-time and contribute to reduction in the nocturnal air temperature in the city.

INTRODUCTION

Emerging economies in Southeast Asia are likely to see serious energy shortages, especially in terms of electricity, due to the recent rapid economic growth. Most of the cities in this region have a hot and humid climate during the summer months, and the growing energy consumption caused by air-conditioning in buildings is, therefore, a major concern. Meanwhile, these cities are suspected of already experiencing urban heat islands (UHIs) as a result of the rapid urbanization. The further rise of urban temperature would lead to a significant increase in energy demand for cooling. Currently, these Southeast Asian cities tend to propose large-scale master plans and increase their urban population. This would result in a dramatic change in land use and therefore the urban climate.

In Hanoi, a long-term urban development plan, namely the Hanoi Master Plan 2030, was implemented in 2011 with the aim of developing the city into a more sustainable capital (VIUP, 2011). One of the key concepts of the master plan is to maintain abundant green coverage in the city through a systematic green network, including green buffers and green belts, for example. Although the master plan had considered various environmental issues such as air pollution, water quality and eco-system, this assessment did not take into account the impact of this development on UHIs in the city.

Therefore, the objective of this study is to investigate the UHI effects in Hanoi under the present land use conditions as well as under those conditions proposed by the master plan, focusing especially on the cooling effects of the green strategies. Numerical simulations, specifically meso-scale urban climate modelling using Weather Research and Forecasting (WRF) are performed for this purpose.

HANOI MASTER PLAN 2030

As the capital city of Vietnam, Hanoi is the second largest city of the country, which make up an area of about 3,300 km^2. The city center is located in the delta area along the Red River, which is about 90km inland from the coastal line. Hanoi experiences a typical tropical monsoon climate, comprising a hot-humid season (April to October) and a cool and relatively dry season (November to March). The southeast monsoon wind prevails during the hot season. The maximum monthly average air temperature is observed in June, which is about 30°C, while the minimum average value of about 16.5°C in January.

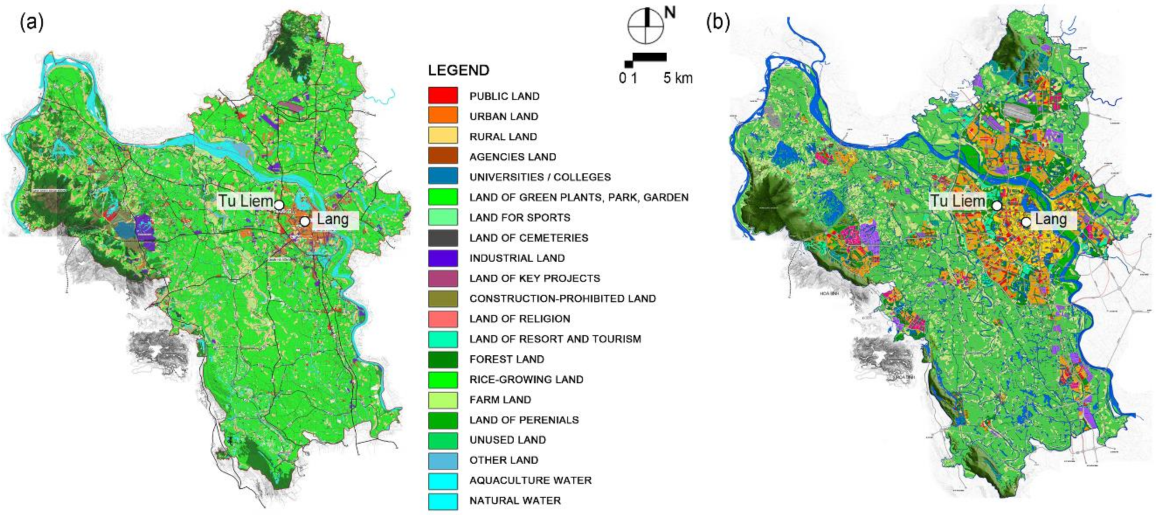

Figure 1 *Land use and land cover for (a) the current status and (b) the Hanoi Master Plan 2030. Source: VIUP, 2011*

The Vietnam government officially implemented the Hanoi Master Plan 2030 in July 2011. In the master plan, the population of Hanoi is projected to reach 9.2 million by 2030. The main target of the master plan is to develop Hanoi as a green-cultured and civilized-modern city. In order to achieve that target, the master plan proposes a series of spatial development strategies for the capital city. One of them is, as described before, the green network consisting of two major green strategies which are the green belts and the green buffers. As a result, the green coverage in the master plan would account for about 52% of the total land of the city. Figure 1 shows the land use changes before and after the implementation of the master plan. To meet the demand of expanding urban development, 28% of the city's natural land will be allocated for urban construction land by 2030. In total, the constructed land will rise sharply by almost three times, from 46,340 ha (14%) to more than 129,500 ha (39%).

DATA AND METHODOLOGY

Weather Research and Forecasting

Meteorological modelling is performed to obtain basic weather elements such as air temperature, humidity, and surface wind, using the Advanced Research Weather Research and Forecasting (WRF-ARW) model (version 3.5) (Skamarock et al., 2008). WRF is a three dimensional non-hydrostatic meso-scale meteorological model developed at the National Center for Atmospheric Research (NCAR) based on the non-hydrostatic compressible form of the governing equations in spherical and sigma coordinates with physical processes, such as cumulus scheme, microphysics, planetary boundary layer (PBL) processes and atmospheric radiation processes, incorporated into a number of physics parameterizations. This model has been widely used in atmospheric research and operational forecasting needs.

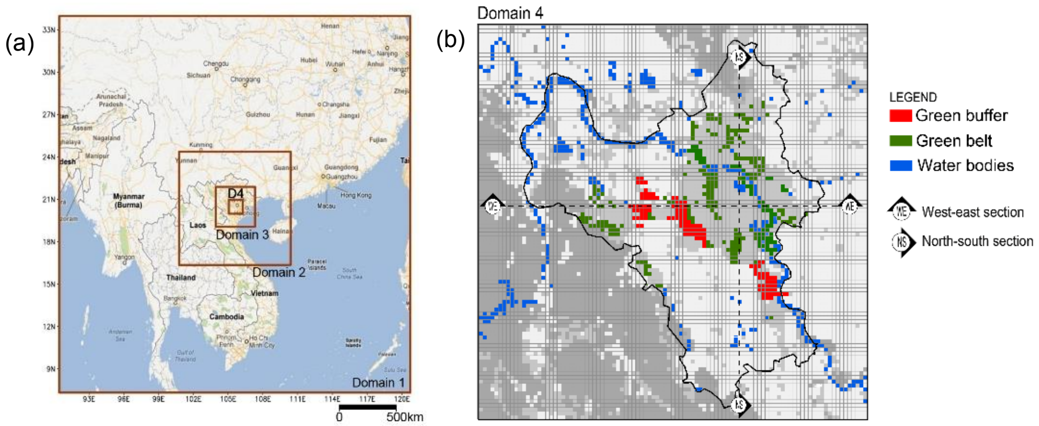

Figure 2 *(a) Computational domains for the WRF simulation. (b) Domain 4 covers all of Hanoi City (100x100 grid points), with 1 km resolution. The green strategy areas are indicated by colors. Green represents the green belts and red is for the green buffers.*

The WRF simulations in this study adopt an interactive grid nesting with four domains that have horizontal resolutions of 27, 9, 3 and 1 km for domains 1, 2, 3 and 4, respectively (Figure 2a). The domain 4 covers all of the Hanoi City (Figure 2b). The 30 sigma levels are set up vertically. The initial and lateral boundary conditions are imposed every 6 hours using the NCEP FNL Operational Global Analysis data with 1°x1° latitude-longitude resolution (http://rda.ucar.edu/datasets/ds083.2/).

Simulation scenarios

As shown in Figure 2b, the green belts are large green spaces located inside the urban development area with the aim of improving the micro-climate conditions, while the green buffers are the boundary space between the existing urban areas and expanded urban clusters. To study the effect of these strategies on the urban climate in the future, a comparison is performed between the current condition (hereafter referred as U_CUR) and the master plan scenario (hereafter referred as U_HMP). Both of the green strategies are implemented in the U_HMP. In order to evaluate the effectiveness of the green strategies, two scenarios are designed which are U_NOGREEN and U_GREEN. In U_NOGREEN, both of the green strategies are not taken into account and converted into the built-up area (Figure 3c). Meanwhile in U_GREEN, the same amount of strategic green areas in the master plan are redistributed to new locations, resulting in smaller green spaces but equally distributed in all of the city (Figure 3d).

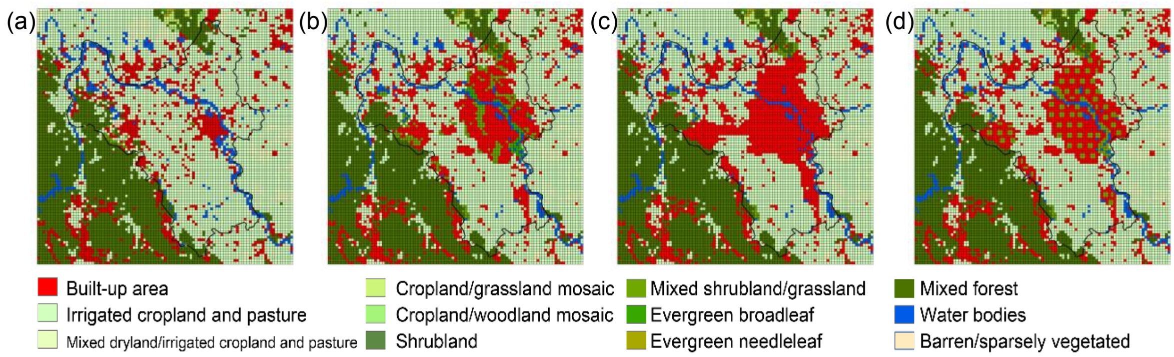

Figure 3 LULC of domain 4 for (a) U_CUR, (b) U_HMP, (c) U_NOGREEN, and (d) U_GREEN.

Model validation

The simulation was conducted for one month from 00:00 UTC 1 to 00:00 UTC 30 June in 2010, which was the hottest period over the period of 2000-2012. Subsequently, simulation results on 17 June of a typical hot sunny day is mainly analyzed in the following sections. Figure 4 presents the comparison of air temperature and wind speed between the simulated and the 3-hourly observation data at Lang station (21.02°N 105.8°E) located in the Hanoi city center (see Figure 1a). Both of the simulated air temperature (at 2 m above ground surface) and wind speed (at 10 m above ground surface) show good agreement with the observed values with a coefficient of determinant of 0.92 and 0.13, respectively. The simulation conditions are shown in Table 1.

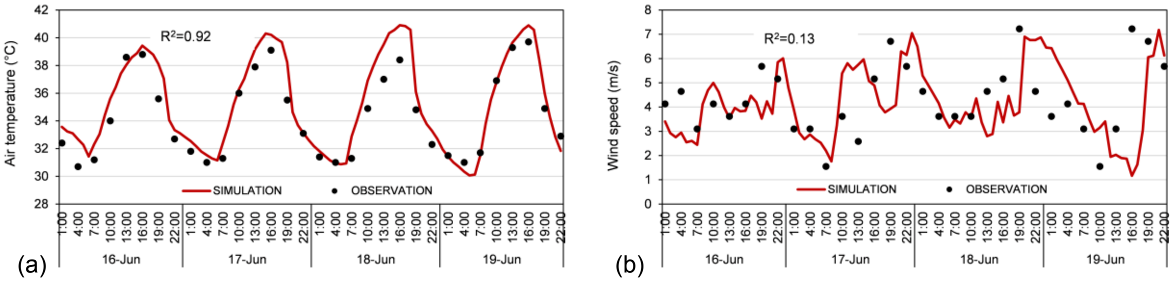

Figure 4 *Comparison between the observed and simulated value for (a) air temperature and (b) wind speed at Lang station located in Hanoi city center.*

Table 1. WRF Simulation Conditions

Items	Conditions
Simulation period	00:00 UTC 1 to 00:00 UTC 30 June in 2010
Vertical grid	30 layers
Horizontal grid	100x100 grids
Meteorological data	NCEP FNL
Land use/land cover (LULC) data	Domain 1 and 2: USGS (default); Domain 3:GLCNMO; Domain 4: ALOS ANVIR-2 and National Digital LULC data
Microphysics	WSM 3-class
Long-wave radiation	RRTM long-wave scheme
Short-wave radiation	Dudhia short-wave scheme
PBL scheme	YSU Scheme
Cumulus scheme	Kain-Fritsch scheme
Surface scheme	NOAH-LSM
Surface layer	Monin-Obukhov scheme

RESULTS AND DISCUSSION

Urban climate in current status and master plan condition

Figures 5 and 6 present the spatial patterns of the simulated air temperature at 2 m above the ground surface and the winds at 10 m above the surface for U_CUR, U_HMP, U_NOGREEN and U_GREEN at 1:00 and 16:00 LST on 17 June, respectively. This section compares U_CUR and U_HMP. At night, the highest air temperature is observed not in the city center but in the lee of western mountainous region in both scenarios (Figure 5). This result is partly due to the effect of Foehn wind from Laos (Nguyen & Reiter, 2014). As shown in Figures 5 and 6, westerly or south-westerly winds prevail most of the day in the western mountainous region. While these westerly winds pass over the mountain range situated near the border of the Hanoi region, the air gets drier and the temperature increases rapidly. These westerly winds flow over most parts of the simulated area during the daytime (9:00-17:00) and bring hot and dry air to the city. In contrast, relatively cool south-easterly or southerly winds prevail over plain areas in the east of 105.65°E during the night-time (18:00-8:00) (Figure 5).

In U_CUR, the minimum nocturnal air temperatures in urban and suburban areas are recorded as approximately 31-32°C, while the air temperature is approximately 32-33°C in the lee of mountainous areas. The daily peak air temperatures were obtained in most parts of the city around 16:00 in both conditions (Figures 6a and 6b). Although the peak air temperatures remain almost the same level even after implementing the master plan, the high air temperature areas of 40-41°C expand widely over the planned built-up areas in U_HMP. At 1:00, the air temperature difference between U_CUR and U_HMP increases by up to 2-3°C over the expanded built-up areas under the master plan condition. During the daytime, the increase in air temperature over the expanded built-up areas is not significant, which is up to 1°C, compared to that in the night-time.

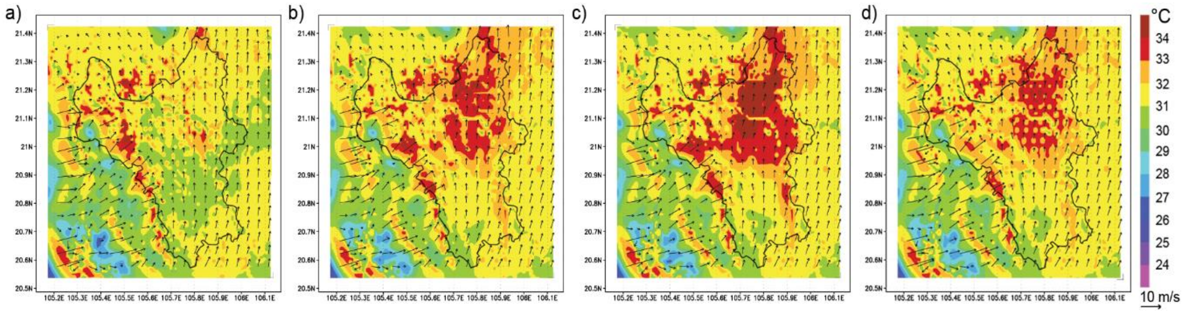

Figure 5 *Air temperature and wind distribution at 1:00 on 17 June for (a) U_CUR, (b) U_HMP, (c) U_NOGREEN, and (d) U_GREEN.*

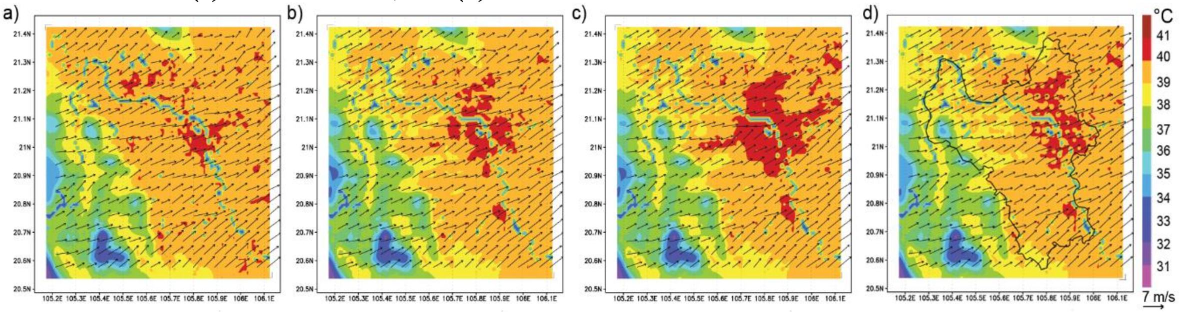

Figure 6 *Air temperature and wind distribution at 16:00 on 17 June for (a) U_CUR, (b) U_HMP, (c) U_NOGREEN and (d) U_GREEN.*

Master plan condition and that without green network

In U_NOGREEN, the planned green spaces are turned into the built-up areas. As expected, the high air temperature areas of 33-34°C are enlarged over the expanded built-up areas at 1:00 (Figure 5c), while the high air temperature areas of 40-41°C are found over the same expanded built-up areas at 16:00 (Figure 6c). The increase in air temperature in the built-up areas becomes noticeable during the night-time (1:00), with the maximum increase of 1°C from U_HMP to U_NOGREEN. The incremental zones of the air temperature from U_HMP to U_NOGREEN correspond to the expanded built-up areas and those transformed from the planned green spaces.

The diurnal average air temperatures of seven days (13-20 June) in Lang and Tu Liem for three scenarios are shown in Figure 7. These two locations represent the existing city center (Lang) and the green areas located in the green belt (Tu Liem), respectively (see Figure 1a). As shown, the average air temperatures for U_CUR and U_HMP at Tu Liem are lower than the corresponding air temperatures at Lang by up to 1°C during the night-time and by up to 0.5°C during the daytime, respectively. This is mainly due to the difference of land cover between the two places. Tu Liem still maintains the natural land cover (i.e. mixed shrubland or grassland) even after the implementation of the master plan. However, if all the green areas are converted to built-up areas, the air temperatures at Tu Liem are increased significantly by up to 1.5°C at night, reaching the similar values to those at Lang. Meanwhile, the removal of green strategies results in a slight increase in the average air temperatures in the existing city center (i.e. Lang). As shown in Figure 7a, the nocturnal average air temperatures in U_NOGREEN are approximately 0.3°C higher than those in U_HMP.

As shown in Figure 7, in both Lang and Tu Liem, the average air temperatures in U_CUR increase slightly faster than those in the other scenarios during the morning hours from 8:00 to 10:00. This occurs, although not prolonged, probably due to the difference of heat capacity of the whole urban fabric between U_CUR and the other scenarios. Thermal capacity of the whole urban surface is largely increased by the expansion of the city, which in turn, slows the increase in air temperature during the morning in the cases of U_HMP and U_NOGREEN than that in U_CUR. On the other hand, the green areas induce a relatively faster heat release as illustrated in Figure 7b. As shown, except for the above mentioned morning hours, the average air temperatures in U_CUR and U_HMP in Tu Liem are significantly lower than those without the green areas (U_NOGREEN). Nevertheless, the proposed green areas do not result in the large reduction in air temperature at Lang because the city center is located 4 km away from the green belt.

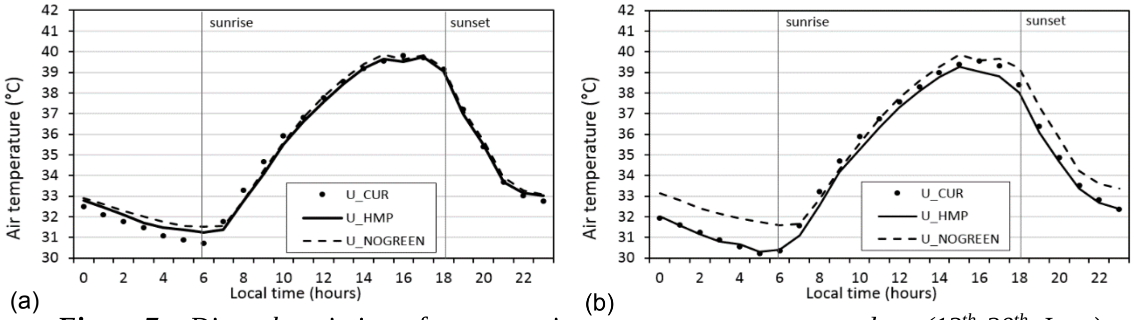

Figure 7 *Diurnal variation of average air temperature over seven days (13^{th}-20^{th} June) at (a) Lang and (b) Tu Liem.*

Impacts of the distribution of green spaces

Figure 8 shows the air temperature distribution over the built-up areas in U_HMP and U_GREEN at 1:00 and 16:00 on 17^{th} June 2010, respectively. As shown in Figure 8a, the nocturnal air temperatures in the built-up areas range from 31-34.5°C, with the proportion of the area at specific temperature peaking at 33.5°C. In U_GREEN, the proportions of the area with the air temperature of 32.5-34°C are reduced, while the proportions of the area with the lower air temperatures of 31-32°C are increased. This air temperature shift indicates the reduction in UHI intensity after the green spaces are equally distributed within the city. In the daytime, the amount of areas with the air temperature of 39.5°C is reduced and shifted down to the ranges of 38.5-39°C, indicating the temperature reduction by 0.5-1°C (Figure 8b). The impact of the relocation of the green spaces on the reduction of UHI intensity is greater in the night-time than that in daytime.

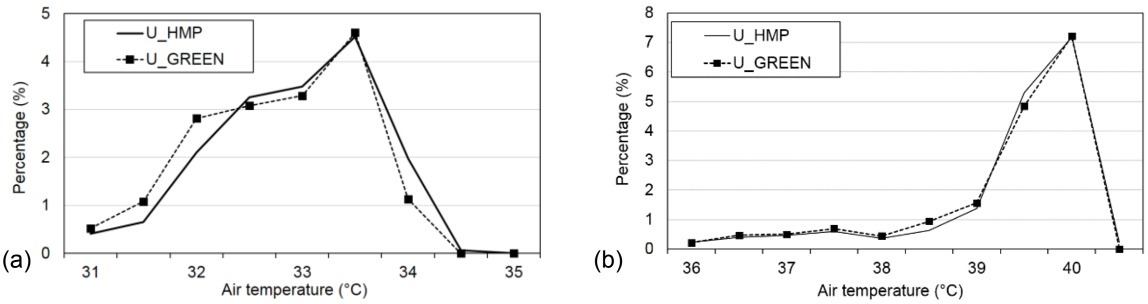

Figure 8 *Air temperature distribution over the built-up areas on 17^{th} June at (a) 1:00 and (b) 16:00.*

Effects of prevailing winds

Figure 9 depicts wind roses at the city center (Lang) over the one month simulation period (June 2010) analyzed by the corresponding air temperatures (a, b) and the wind speeds (c, d) at 10 m above the ground surface during the daytime (09:00-17:00) (a, c) and the night-time (18:00-08:00) (b, d), respectively. It is noted that the three scenarios did not show any remarkable differences in terms of ground surface wind conditions (see Figures 5 and 6). Therefore, the data from U_CUR are analyzed in this section.

As seen in the previous section, the southerly and south-easterly winds with relatively high wind speeds of 4-7 m/s prevail during the night-time over the whole month (Figure 9bd). In contrast, the prevailing wind direction differs during the daytime as shown in Figure 9ac. The westerly or south-westerly winds prevail over approximately 38% of the month (Figure 9ac). Nevertheless, the north-easterly and south-easterly winds also prevail during the same period. It is interesting to note that when the westerly or south-westerly winds blow over the city center, the air temperatures are relatively higher (38-41°C) than the air temperatures under the conditions of north-easterly or south-easterly winds (28-40°C), though the corresponding wind speeds do not differ significantly between the different wind directions (Figure 9ac). This result supports the assumption that urban air temperature in Hanoi is increased when the westerly or south-westerly Foehn winds flow over the city during the daytime.

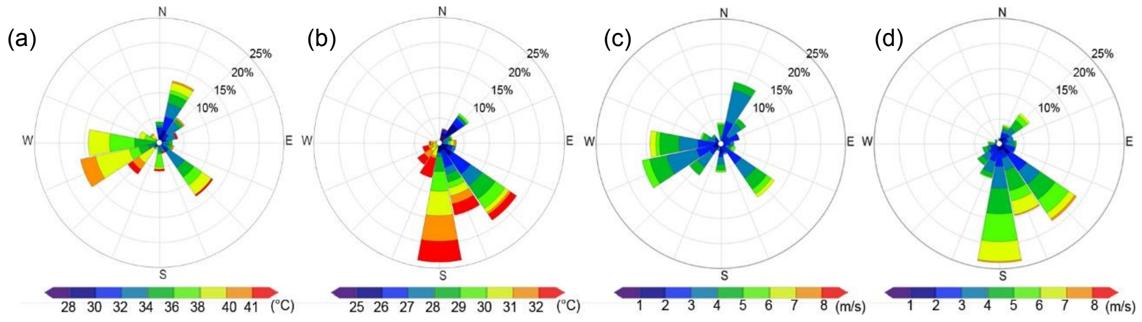

Figure 9 *Wind roses at Lang station in June 2010, analyzed by (a) air temperature (daytime), (b) air temperature (night-time), (c) wind speed (daytime), and (d) wind speed (night-time).*

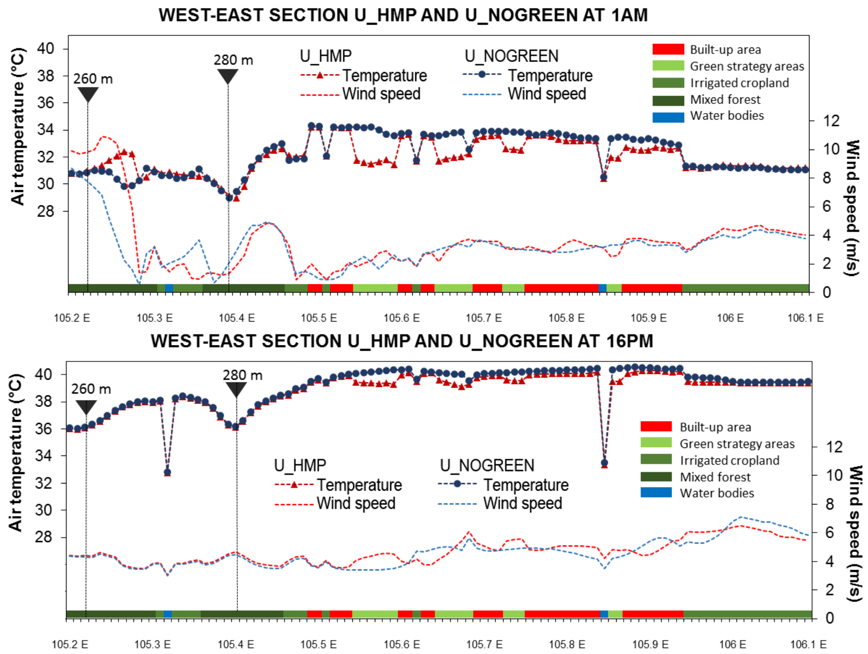

Figure 10 *Variations in the simulated air temperature and wind speed from U_HMP and U_NOGREEN along the west-east cross-section of the meridional line at 21.04°N.*

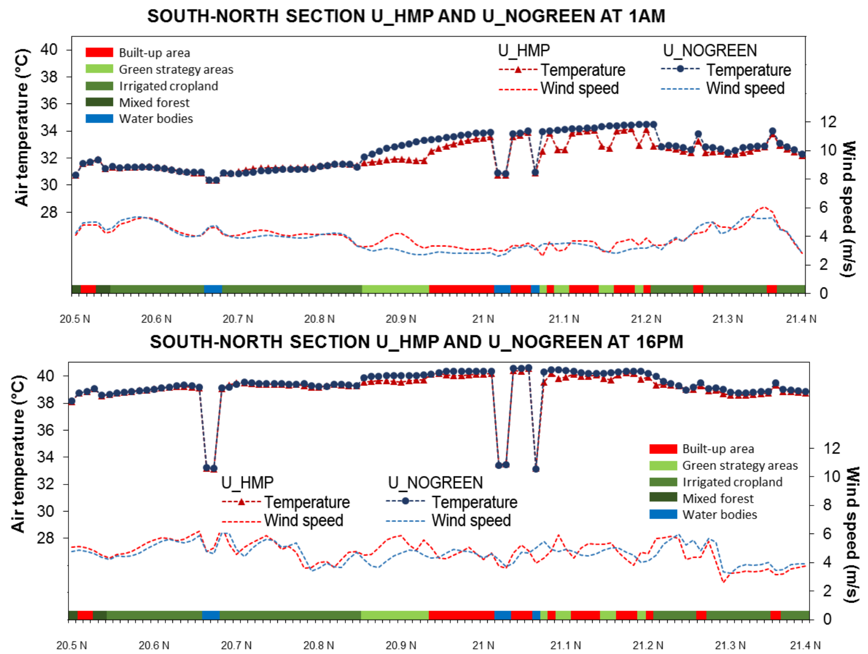

Figure 11 *Variations in the simulated air temperature and wind speed from U_HMP and U_NOGREEN along the south-north cross-section of the meridional line at 105.81°E.*

Figures 10 and 11 show the spatial variations in the air temperature and wind speed along the cross sections (see Figure 2b) of domain 4 from U_HMP and U_NOGREEN on 17 June. The horizontal indicator for the LULC category in each panel is based on the master plan. Therefore, from Figures 10 and 11, the effects of the green spaces and surface winds on the air temperature can be discussed. This cross-section traverses two mountains at heights of approximately 260 m and 280 m in the western region at 105.22°E and 105.40°E, respectively.

The discrepancies between the air temperatures in the strategic green areas under U_HMP and the built-up transformed areas in U_NOGREEN are large, up to 2-3°C, when the relatively strong and cool southerly winds prevail at 1:00 (Figure 10a). In this circumstance, the reduction in the air temperature due to the effect of the green strategy can be observed in some parts of surrounding built-up areas, up to 1°C. These discrepancies are reduced in the daytime as the wind direction changes from the south to the west (Figure 10b). The surface wind conditions largely affect the air temperature distribution. As shown in Figure 10a, the leeward sides of both mountains receive relatively higher westerly winds and the air temperature increase while flowing down the slopes of the mountain at 105.4°E (i.e. the Foehn effect).

The southerly winds flow from the coastal area and pass through the irrigated croplands in the south at 20.85°N and bring relatively lower air temperature before entering the urban areas (Figure 11a). From the above point, the air temperature in U_NOGREEN gradually increases towards the north and then rapidly decreases. Then, the air temperature simulated in U_NOGREEN depicts a direct and linear response to the corresponding winds (Figure 11a). The cooling effect of the surface wind are clearly seen when the air temperature in built-up areas over the eastern half from 105.65°E drops by nearly 1°C particularly when the southerly winds prevail at night (see Figure 5ab and 10a)

CONCLUSIONS

Based on the results of the numerical experiments, the main findings are summarized as follows:

1. In general, the daytime peak air temperature rises up to 40-41°C over the built-up areas in the city center in the current condition.
2. If the LULC is changed according to the master plan, the daytime peak air temperature is predicted to remain at almost the same level as the current condition. However, the new hotspots would expand widely over the planned built-up areas.
3. The strategic green spaces would not sufficiently mitigate UHIs in the city because they are located far away from the city center. On the other hand, the equally distributed green areas show a better performance in the reduction of UHI intensity, especially at night.
4. The south-westerly or westerly winds are dominant in the daytime and bring hot and dry air to the city, likely due to the Foehn wind. The air temperature in Hanoi City is increased when these Foehn winds flow over the city during the daytime. The occurrence of this phenomenon was found to be approximately 38% in June 2010. In contrast, relatively strong and cool southerly winds prevail during the night-time and contribute to reduce the nocturnal air temperature in the city. Due to the discrepancy in term of wind condition, heat islands appearing in the western built-up region of Hanoi are found to be more intense than in the city center at night.

ACKNOWLEDGMENTS

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Tall Buildings and the Urban Microclimate in the City of London

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ABSTRACT

The design of tall buildings can be quite complex not only in architectural, structural or façade system terms but also in their interrelations with the environment. Recent design developments have shown a growing consideration for this micro-climate interface as a part of a sustainable design strategy for tall buildings towards bioclimatic urban fabrics. Architects and urban planners recognize that the importance of activities at street level is a constant reality. Many efforts are made to develop sustainable skyscrapers where the co-relation with the surrounding environment influences the architecture, land use pattern, public realm and street activities. The aim of this study is to understand the environmental or bioclimatic factors, which take part in the creation of microclimate relations between tall buildings and the urban city fabric. The research includes a brief understanding of bioclimatic design of tall building focusing in its relation to surrounding neighbourhoods. The impact of environmental factors namely wind flow patterns around buildings, daylight availability and overshadowing, air temperature and humidity, as well as the urban heat island phenomena, landscape and albedo of materials, vehicular & pedestrian movements and activity patterns at street levels in tall building clusters is addressed. A series of environmental variables measured during summer and simulated results of Canary Wharf and Liverpool Street clusters are compared to understand how the urban microclimates are affected within two different urban fabric typologies in London. Outcomes of literature review and these two case studies give useful guidelines to be utilized in the process of Sustainable urban design.

INTRODUCTION

Cities all around the world are recognized by their skylines (**Figure 1**) and there are many drivers to its growth. Land scarcity and high real estate value, commercial opportunities and corporate demand, as well as the attraction to the cluster are often allied with a growing city population and its social needs.

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Figure 1 Canary Wharf skyline, London.

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The City of London is a world financial centre and needs to project an image of power and efficiency. The scarcity of land within the neighbourhood is further restricted by a surrounding mesh of residential buildings, on average with less than 3 floors (London has around 52% dwelling of the type terraced, semi detached and detached). High rise buildings being structures with 12 floors minimum contrast significantly with the low height London residential stock. According to the England housing survey, London only has 20% of dwellings that are 3 or more storeys in height. (EHS, 2012) This contrast with high-rise clusters developed within the city and in particular in the city of London neighbourhood (Canary Wharf Tower is 235m height). Tall buildings in a cluster are a growing tendency as a solution to the need of office space within the limited land available. The Greater London Authority promotes this concept as an efficient way to build offices that need to be energy efficient and with good public transport access and capacity, in line with sustainable cities and the Agenda 21. (GLA, 2014)

This creates an opportunity for sustainable development in a holistic approach that goes beyond the architecture, structural or façade system to include the interface between the street environment and the building. Recent design developments have shown major consideration over this microclimate interface as a part of a sustainable design strategy for tall buildings in the direction of making bioclimatic urban fabrics.

Likewise local climate variations influence the urban boundary and should be given much thought. The amount of solar radiation can be significantly reduced in urban areas as a result of overshadowing, air pollutants and wind flow patterns adding to the greenhouse effect. The Urban Heat Island phenomenon can be aggravated by high-density materials, surfaces with low albedo, reduced green spaces (evapotranspiration) and anthropogenic heat. This impacts the surface and air temperatures near the ground. Conversely high-rise buildings require special attention to the effect of strong winds at high levels. At street level wind may be much reduced overall (though it may increase locally due to a 'wind tunnel' effect) and buildings casting shadows may create dark and cold spots for pedestrians. The character of the urban cluster / fabric play a big role in such microclimates. (Littlefair, 2000; Erell, 2011)

BIOCLIMATIC DESIGN CONSIDERATIONS FOR URBAN FABRICS WITH TALL BUILDINGS

The effect of climate on the activities of occupants and its health is the base of Bioclimatology. The bioclimatic design approach is not limited to the building but extends beyond and involves external environmental conditions, site location, geography, surrounding buildings and their aesthetic expressions, land use pattern, the neighbourhood cluster, public accessibility and activities. (Clair, 2010) The major bioclimatic design considerations for high-rise clusters are:

a. Urban geometry (**Figure 2**): variation in heights and in-between distances of buildings (street canyon);

b. Local climate: external air temperature, relative humidity and prevailing wind direction and speed;

c. Orientation and overshadowing (**Figure 3**): position of tall buildings with respect to south (northern hemisphere) and its exposure to solar radiation and overshadowing over low-rise buildings within the cluster;

d. Solar access, solar radiation and albedo (**Figure 4**);

e. Urban canyons (**Figure 5**).

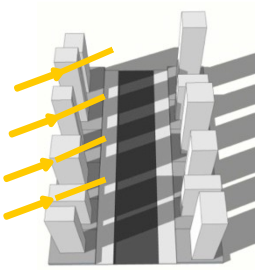


Figure 2 Urban Geometry.

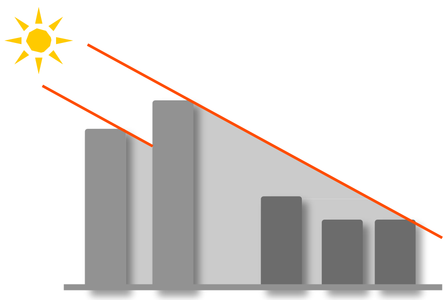


Figure 3 Orientation and Overshadowing.

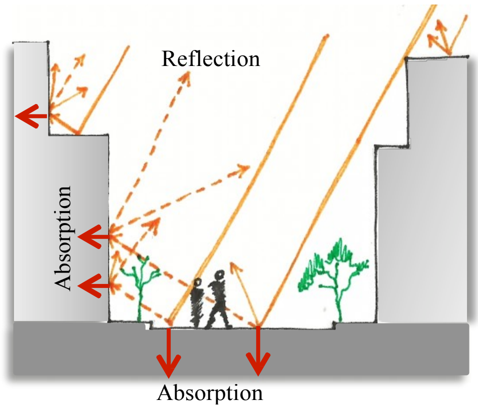


Figure 4 Solar radiation and albedo.

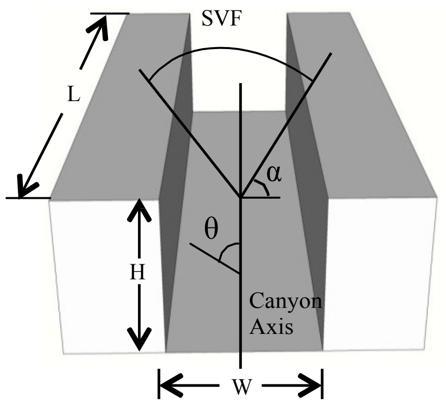


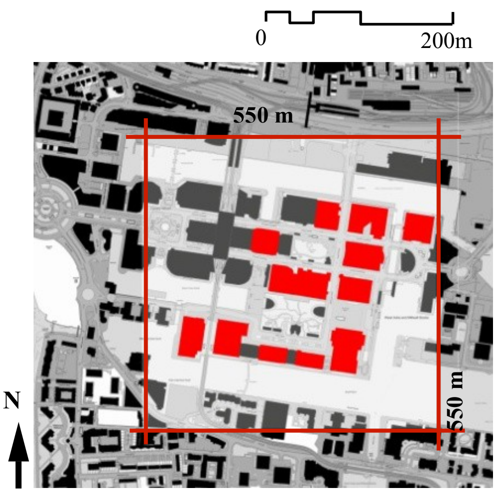
Figure 5 Urban canyon.

CASE STUDIES

This study assessed two different high-rise urban typologies in London to understand the interaction/impact of buildings at the urban scale. Results from simulations as well as real data recorded in a summer period are presented next.

Cluster 1: Canary Wharf, London Coordinates: 51.5036° N 0.0183°W for 1 Canada Square, **Figure 6**

Solar access and solar radiation: The Central garden is the biggest open space within the Canary Wharf cluster. It works as a 'buffer space' as a result of the microclimate conditions originated within these high-rise buildings of the square. The average direct solar radiation ranges from 120Wh to more than 1200Wh during the summer months from June to August. **As seen in Figure 7**, the road along the edge of the south buildings receives very low radiation during day time (9 am to 5 pm), around 120Wh, while the open space in front of plaza receives much higher levels of solar radiation as facing buildings are distant enough to avoid significantly overshadowing. This correlates well with the monitored air temperature made at the plaza, the garden and the south-west corner low rise block during July 1st to July 13th 2011 as seen in **Table 1** and elsewhere (Pandya, 2011).



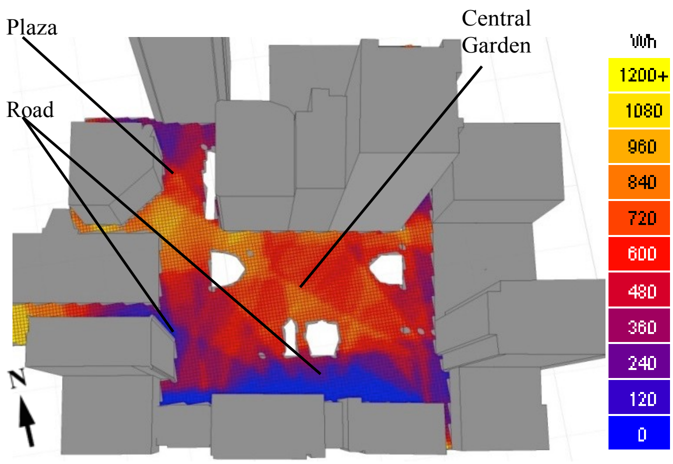


Figure 6 Canary Wharf cluster. **Figure 7** Direct solar radiation – June, July, August 9am to 5pm.

The simulation results of direct solar access on vertical surfaces, **as shown in Figure 8**, reveal that the 'unobstructed' south edge buildings receive almost 6000Wh/m2 during Summer solstice. Buildings on the north side of the central garden have much lesser solar access. This amounts to around 2000Wh at ground level, increasing to around 4000Wh on top of the façade, as surrounding buildings no longer significantly obstruct high storeys. This has an impact on temperature and daylight availability to the spaces.

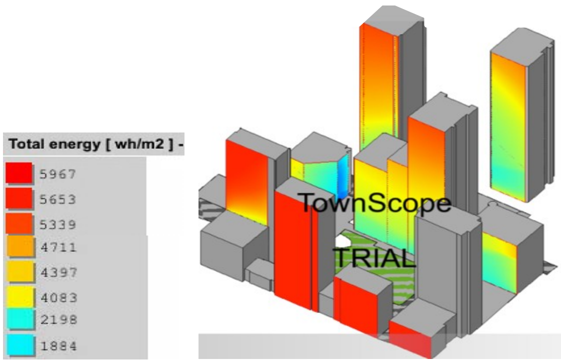
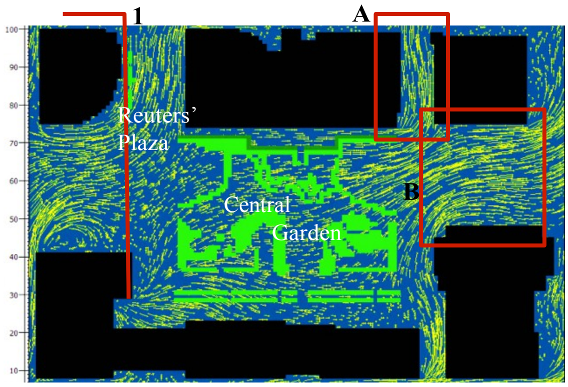


Figure 8 Solar access on Summer solstice.

Urban Air Flow: For both clusters, CFD Simulations with ENVI-MET software were made. Results are presented for July 1st at 9am. The average wind speed is 3m/s and the prevailing wind direction in July is southwest (as per meteorological data for London). **Figure 9,** location A highlights that within the narrow canyons the wind flow vectors are longer which means high speed, while at the open spaces such as Reuters' plaza or at the central garden, the wind speed is less intense and there are no significant deviations in the direction as a result of lack of obstructing tall buildings.



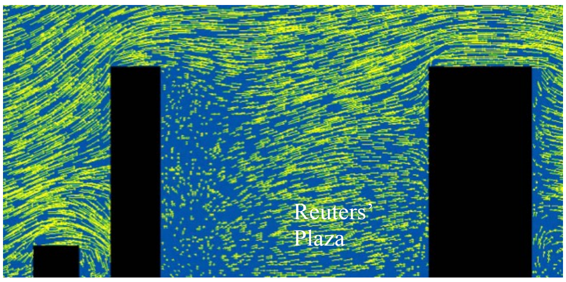


Figure 9 Wind flow simulation plan on July 1st, 9am. **Figure 10** Wind flow simulation - Section 1.

Figure 10 shows that when buildings are fairly distant, downward wind loses its speed when it enters the larger open space. As it reaches the opposite high-rise building, the speed increases gradually. At the Canary Wharf cluster the corners of the buildings or edge conditions are most affected by incoming wind with higher speeds and get deviated due to obstructing edges as seen in **Figure 9**. This generates wind turbulences with high wind speed (**see Figure 11**). As both north and south edges are blocked by high-rise buildings **(Figure 9,** location: B**)** wind turbulence and speed increases.

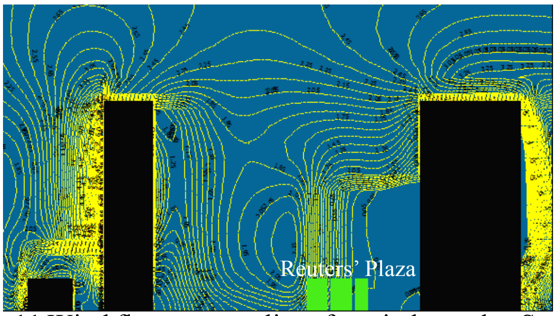


Figure 11 Wind flow contour lines for wind speeds - Section 1.

Cluster 2: Liverpool street, Bishopsgate, London Coordinates: 51.31° N, 0.4° W, **Figure 12**

Solar access and solar radiation: Liverpool Street is surrounded along their edges with continuous building facades. These urban canyons are mainly oriented 20° to 26° from north. **Figure 13** shows that narrow streets, having smaller canyon ratios (width to height) receive a smaller amount of direct solar radiation (street in front of Tower 42). The plaza, an important public space in the neighbourhood, receives more than 2500Wh.

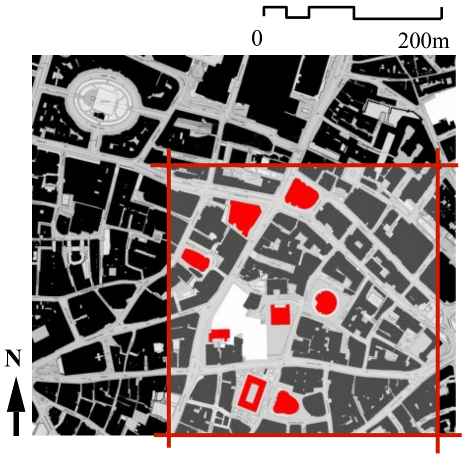


Figure 12 Liverpool street, Bishopsgate cluster

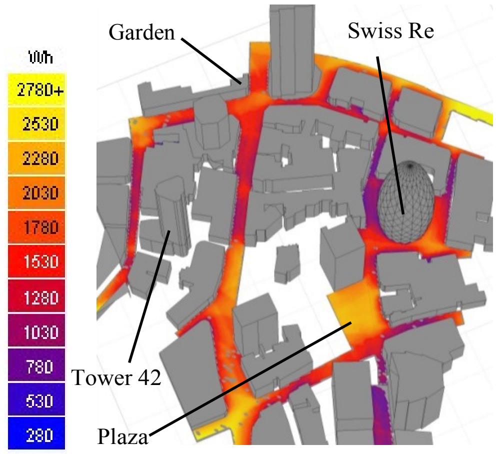


Figure 13 Direct solar radiation - June, July, August. 9am to 5 pm

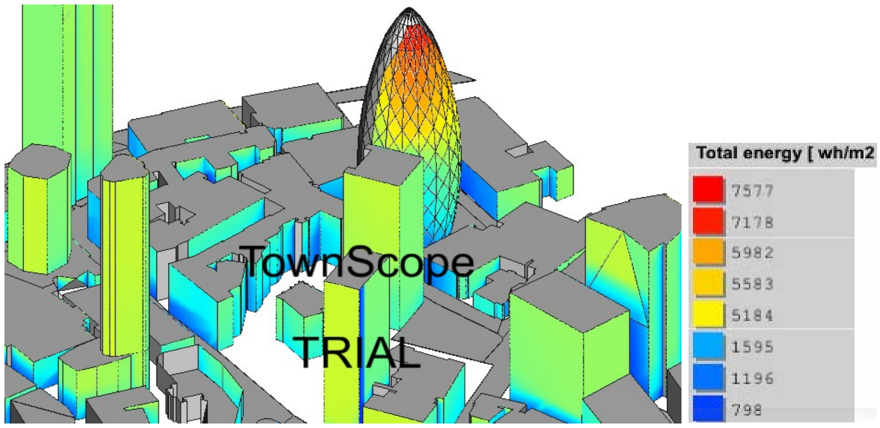


Figure 14 Solar Access on Summer solstice

In case of the Swiss Re building, the rear open space is used as a café and restaurant esplanade during summer, as it benefits form direct sun from southeast and south. This is not the situation at the front entrance as it is blocked by continuous buildings, and solar radiation is reduced to 500Wh. **Figure 14** shows that the orientation of canyons/streets and buildings heights along the edge of them, can significantly affect the solar access at ground level, from 400 to 1500Wh/m2. Solar access on the façade at higher floors can reach 7500Wh/m2. At this cluster most of the high-rise buildings are fully glazed with anti-reflective glass, other surfaces also have reduced albedo. This prevents a high amount of solar radiation to be reflected towards the surrounding cluster. Conversely it may minimize problems of reflected glare. However, it is likely to increase the cooling loads of the spaces as well as aggravate thermal stress at the façade.

Urban Air Flow: The irregular urban geometry of the Liverpool street cluster, with varying canyon orientations and monotonous flat building fabrics, shows dramatic changes in wind flows. **Figure 15**, Location A – Bishopsgate road is a narrow canyon with building heights around 25 to 40m. The length of the canyon is about 65m and its orientation is southwest to northeast. This geometry permits the southwest wind with high speed entering the canyon. **Figure 16**, Section 1 shows airflow vectors going in the negative direction, upward, as a result of the close vertical surfaces on both sides of the in-between space. As the aspect ratio (H/W) is quite high, the incoming wind speed is higher than the one flowing above the roof of the building.

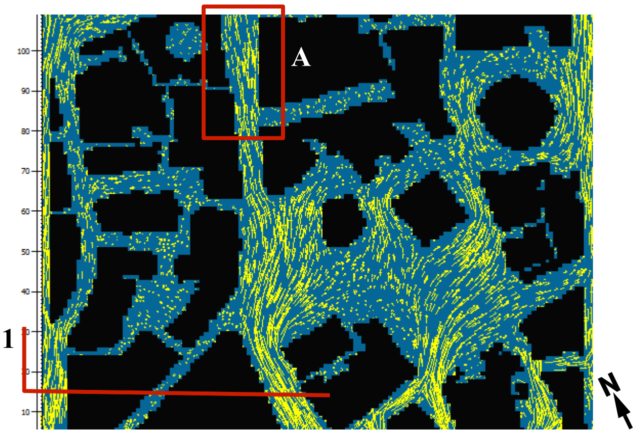
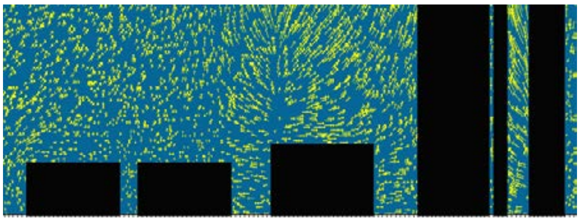


Figure 15 Wind flow simulation on 1st July at 9am.



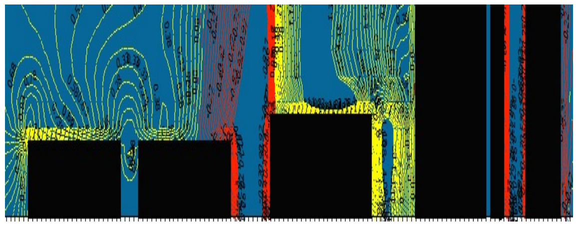


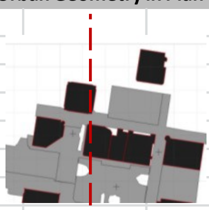
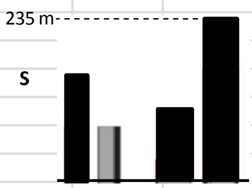
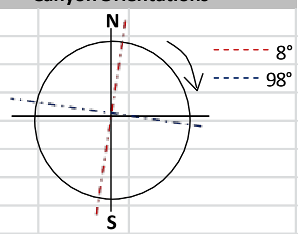
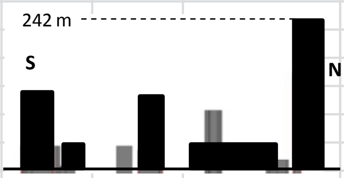
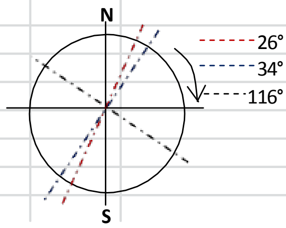
Figure 16 Wind flow simulation - Section 1. **Figure 17** Wind flow contours for wind speed - Section 1.

The irregular street pattern and building edges create negative turbulences **(Figure 17)** that affect the wind flow and speed. This phenomenon is stronger around tall buildings.

COMPARATIVE ANALYSIS

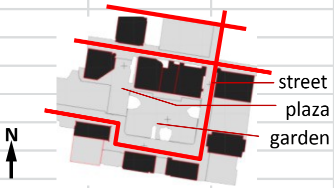
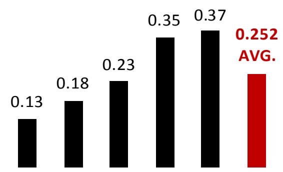
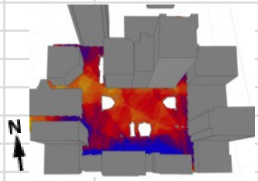
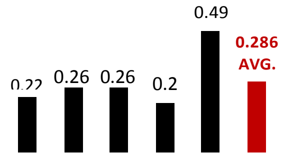
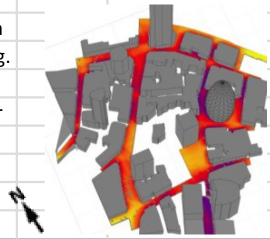
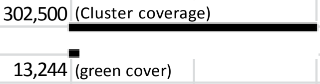
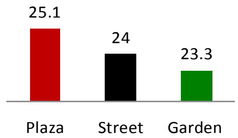
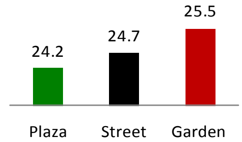
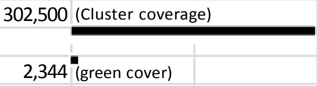
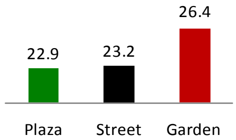
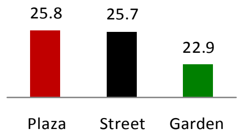
Table 1 Comparative analysis of Canary Wharf & Liverpool Street clusters, London.

Clusters	Total Built up area (m²)	High Rise building foot print (m²)	Tall building Height range (m)
Canary Wharf	302,500 (Cluster coverage) 67,624 (built---up)	302,500 (Cluster coverage) 35,769 (built---up)	235, 200, 153, 140, 105
Liverpool Street 302500 m²	302,500 (Cluster coverage) 158,114	302,500 (Cluster coverage) 16108	242, 180, 125, 100, 93

Clusters	Urban Geometry in Plan	Urban Canyon profiles	Canyon Orientations
Canary Wharf			
Liverpool Street			

The urban geometry of the Canary Wharf cluster has a regular organization of buildings along the road edges with open spaces within. The Liverpool Street cluster presents an irregular street pattern and the building footprint follow the available space. **As seen in Table 1**, the cross sectional profiles of canyons within Liverpool Street cluster are narrower on the north-south axis and the scattered high-rise buildings pop up in the low-rise settlement. This kind of geometry shows uneven height variations in the cross sectional profile of the canyons.

Table 2 Comparative Analysis of Canary Wharf & Liverpool Street clusters, London.

Clusters	Street Pattern	Sky View Factor	Direct Solar Radiation Map
Canary Wharf			1200 Wh max. avg. for summer months 
Liverpool Street			2280 Wh max. avg. for summer months 
Clusters	**Green Cover (m²)**	**Air Temperature (°c) 01/07/2011**	**Relative Humidity (%) 01/07/2011**
Canary Wharf			
Liverpool Street			

The garden area of Liverpool Street shows higher air temperature and lower humidity than the street and plaza places (lowest temperature and high relative humidity). Conversely the Canary Wharf garden has lower air temperature and higher humidity than other parts of the cluster. Similarly, the open space like the plaza has higher wind speeds and the garden has lower wind speed due to the trees blocking the landscape.

The variations in wind speeds at different places is also dependent on the prevailing wind direction and the urban fabric characteristics such as building heights, vegetation, water body and so on.

The comparison of spot measurements of air temperatures at the three locations: plaza, streets and garden areas, revealed that the plaza at Canary Wharf has high air temperature during afternoon hours. **See Table 2.** This is a result of the hard paved surfaces with high reflectance and better solar exposure versus a more shadowed garden with high evapotranspiration. The Liverpool Street plaza appears to be more affected by the proximity of the surrounding buildings, their irregular geometries (ie more surface area) with low surface reflectance and higher thermal mass, hence absorbing more direct solar radiation. Heat is released to the air later at night when temperatures are lower. The open space is also more in the shadow. Therefore during day the air temperature remains low.

Taking this study in consideration the most prominent bioclimatic factors affecting the urban microclimate are: urban geometry, urban canyons, sunlight availability and solar radiation, urban air flow, urban landscape and urban air quality and surface materials. It is understood that all are interdependent. However, the geometry, orientation and fabric of the buildings strongly impact the amount of solar radiation being absorbed/reflected by building facades and streets. The climatic conditions and building geometry play a major role at promoting sunlight availability, ameliorating air temperature and promoting air flow/ventilation to spaces.

CONCLUSIONS

Environmental factors such as air temperature and humidity, wind speed and direction, solar radiation and daylight conditions, noise and air pollution at ground level can make open areas in cities an appealing and comfortable place for pedestrians. Results presented above discuss the influence of these factors within two high-rise clusters in London. Furthermore, they strongly impact the energy performance of surrounding buildings and its comfort conditions and should be given much thought towards sustainable urbanism within existing and future cities.

Canary Wharf has a rich landscape planning in terms of public realm, environmental sustainability, ecology and usage. The central garden permits solar access, a pleasant airflow and acts as a sound barrier from busy roads nearby. Road includes coniferous trees, which helps disperse the pollution particles within the canopy layer. Deciduous trees at the street side provide protection from direct sun and wind turbulence whilst still allows air movement between the trees and the adjacent buildings for ventilation.

Liverpool Street has a compact and dense urban fabric with reduced open spaces, which can be used for urban landscape. Trees in internal courtyards of buildings may be beneficial to the building and its users but not at the urban scale. In hot periods, when the temperature rises above comfort level, direct and the reflected solar radiation from building surfaces increase the Heat Island effect. To minimize this, soft paved surfaces such as sand gravels or green patches of lawn and tree cover are necessary. Climate resilience and demands for sustainable living are not limited to environmental friendly building design, but requires much more attention to bioclimatic factors affecting the urban fabric and its microclimate. Bioclimatic factors can be man made or organic but ultimately affect human living conditions and the environment. It is a necessity to tackle at both building and urban scale.

ACKNOWLEDGMENTS

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NOMENCLATURE

θ = the line running north-south and angle between canyon axis which determines the orientation of urban canyon
W = width of street
H = average height of buildings on both sides
L = length of canyon
α = angle between building top edge and street plane
SVF = sky view factor

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Baseline Scenario of Energy Consumption of Urban Multi- Storey Residential Buildings in India

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KEY WORDS:
Urban residential buildings, Energy monitoring, Energy Performance Index

ABSTRACT:

This paper presents results of monitoring of energy consumption in sample urban residential buildings in India. The work was carried out under the Indo-Swiss Building Energy Efficiency Project (BEEP) as background research leading to the development of energy efficiency guidelines for the design of new residential buildings in the composite and warm-humid climatic regions of India.

The work involved:

a) Collection of monthly energy consumption data for a period of 1-year for 732 households in Delhi-NCR (composite climate) and 426 households in Chennai (warm-humid climate).

b) Detailed monitoring of four residential flats (two each in Delhi and Chennai) for one year duration. The monitoring included: discrete logging of hygrothermal properties of individual rooms & ambient conditions; electricity consumption of comfort conditioning equipment like fans, desert coolers and air-conditioners

c) Analysis of the collected data to calculate Energy Performance Index[1] (EPI), monthly energy consumption profiles, share of energy consumption for comfort conditioning etc.

The information from the analysis of monthly energy consumption data and monitoring campaign is intended to be used to define inputs and validate outputs of energy simulation models for typical residential flats in the two climatic regions. The energy simulation models will be further used to evaluate the potential of passive and active strategies for reducing energy consumption and improving thermal comfort in the residential buildings.

[1] Energy Performance Index (EPI) for the analysis in the paper is defined in terms of annual purchased electricity (in kWh) divided by built-up area (in m^2) of the flat. The built-up area includes covered area of the flat and does not include balcony areas, semi-covered areas and common areas like lifts and lobbies etc.

INTRODUCTION

India is experiencing an unprecedented urbanization due to the cities transforming into economic hubs. According to 2011 census data, about 31% of the India's population was residing in the urban centers, and this percentage is expected to increase to 40% by 2030. It is estimated that the total constructed built-up area would increase from 8 billion square meters in 2005 to 41 billion square meters in 2030 (about 5 fold increase) (Mckinsey & Company, 2009). This situation is significantly different from the developed countries, where bulks of the buildings are already constructed. This provides both challenges and opportunities to building sector stakeholders to develop this building stock appropriately.

As per CEA report (CEA 2005), residential sector consumes 21% of the total electricity generated in India, which is about 3 times more than that of commercial buildings. One of the reasons for this is that the built-up area of residential buildings is about 7 folds more than that of commercial buildings (Mckinsey & Company, 2009). The energy use intensity of the residential buildings is expected to grow because of increase in air conditioned area, better access to electricity and increase in ownership and usage of appliances.

There is an inevitable rise in the density of residential urban development due to scarcity of land and the desire to curtail suburban sprawl. It is now common for city planning authorities to encourage Floor Space Index (FSI) of up to 4; FSI of 1.5 to 2 is becoming commonplace. As per census data, urban residential household will increase by ~2 folds from 2014 to 2032; Greentech Knowledge Solutions Pvt. Ltd. based on EMPORIS (EMPORIS data, 2014) data projected that during this period the share of highrise building will increase by ~ 5 folds.

CONTEXT AND METHODOLOGY FOR DEVELOPING THE GUIDELINES

The guidelines for residential buildings design will focus on the recommendations for the reduction of operational energy, reduction of embodied energy and improvement of thermal comfort of the residents. The flowchart showing the complete methodology for development of design guidelines for residential buildings is shown in Figure 1. The work presented in this paper concerns only with the monitoring and analysis of monthly energy consumption and is highlighted in grey boxes in Figure 1.

Monthly energy consumption data for one year duration was collected from 732 residential units in Delhi - NCR (from 4 residential complexes) and 426 residential units in Chennai* (from 6 residential complexes) to understand the baseline scenario of energy consumption in the composite climate (represented by Delhi-NCR) and warm-humid (represented by Chennai). The composite[2] and warm-humid[3] climatic regions of India. This constitutes almost two third of the total geographical area of India (see Figure 2).

[2] As per National Building Code 2005, "Climatic zone that does not have any season for more than six months may be called as composite zone". In India, composite climate is characterized by hot summer season and moderate winter season.

[3] As per National Building Code 2005, "Warm-humid climate are characterized by two factors: monthly mean maximum temperature (MMMT) and mean monthly relative humidity (MMRH) percentage. e.g. MMMT above 30 ^{0}C with MMRH of above 55% and MMMT above 25 ^{0}C with MMRH of above 75%

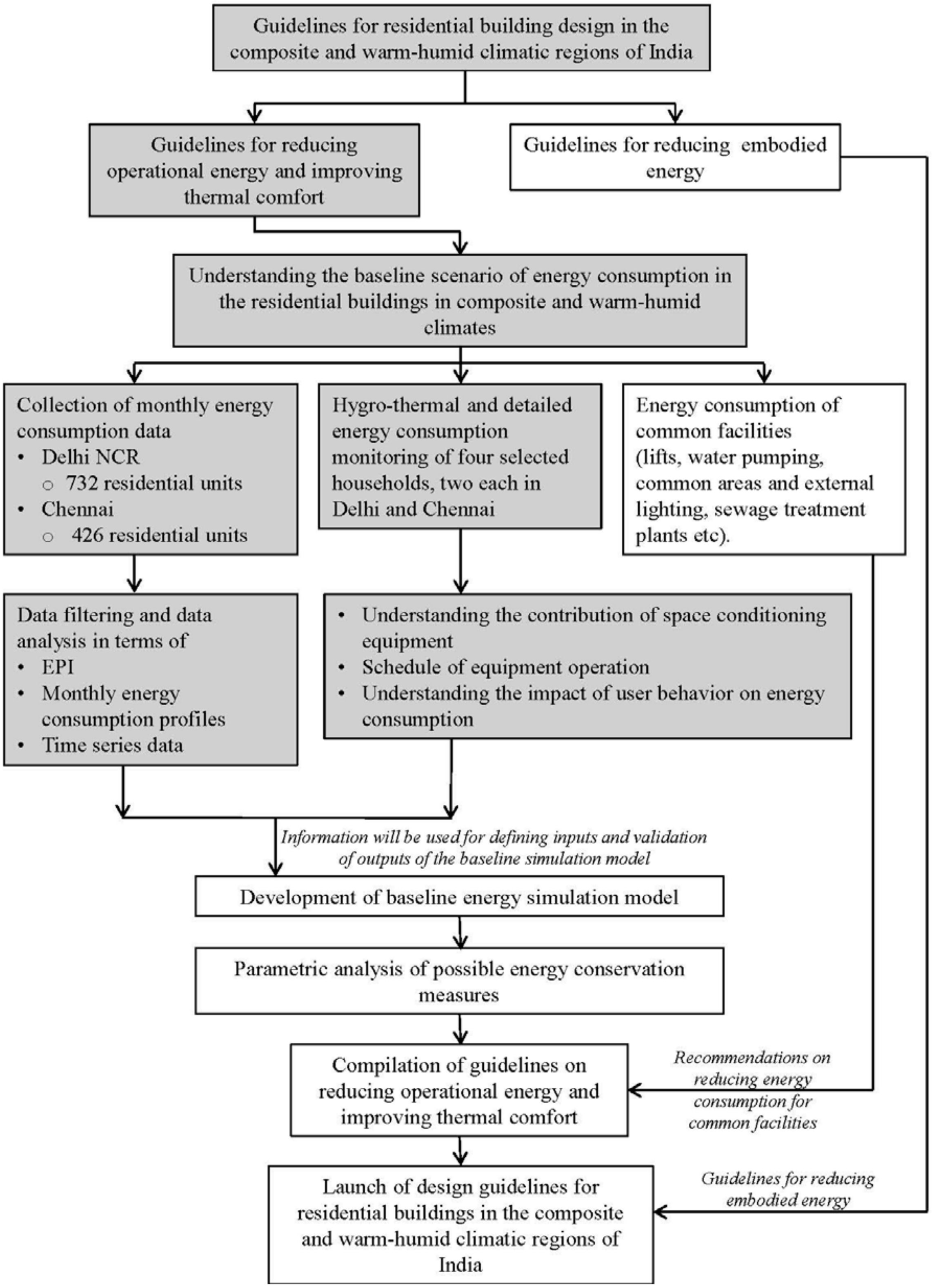


Figure 1. *Flowchart showing approach for development of design guidelines for residential buildings under Indo-Swiss Building Energy Efficiency Project (BEEP)*

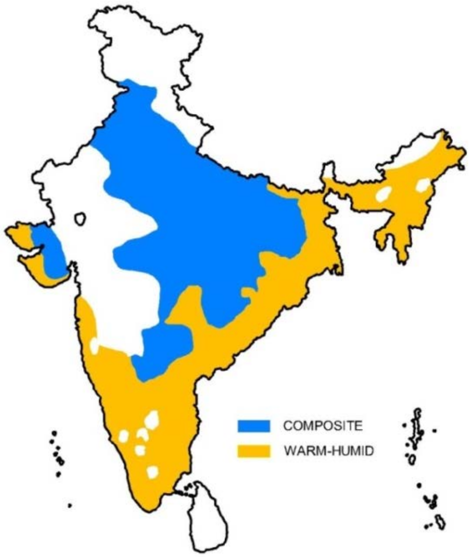


Figure 2 *Climate classification map of India as per NBC 2005*

The selected residential complexes were multi-storey apartment buildings of 3 to 15 storeys. The built-up area of residential units ranged from 80 m^2 to130 m^2. The residential units were having 2 or 3 bedrooms and a drawing/dining room. The residents of these houses primarily represents middle and middle upper income group of India.

A mathematical model was used to filter monthly electricity consumption values, which were either too high or too low. After data filtering, 89% of the data from the residential units in the composite climate and 90% of the data from the warm-humid climate was considered for further analysis. The filtered data was statistically analyzed in terms of Energy Performance Index (EPI) distribution, monthly energy consumption profiles, share of electricity for space comfort conditioning. Time series data (for 2 years) from one of the residential complexes in Delhi was used to infer the trend of energy consumption.

Subsequent to the collection of monthly electricity data, a monitoring campaign was carried out in the four selected residential units (two each in Delhi and Chennai). The monitoring included discrete logging of space and ambient hygrothermal conditions and energy consumption monitoring of space comfort conditioning equipment (Figure 3).

Figure 3 (a) *Temperature humidity logger assembly for monitoring ambient conditions*

3(b) *Globe temperature logger assembly for measuring mean radiant temperature in the room*

3(c) *Energy loggers for monitoring energy consumption of comfort conditioning equipment*

Information from the monthly energy consumption data analysis and monitored data will be used to define inputs and validate outputs of the baseline energy simulation models for both the climatic zones. Potential of individual and group of strategies will be evaluated by conducting parametric runs on baseline simulation models. Inferences drawn from the simulation analysis and recommendations for reducing the energy requirements for common facilities will be used to formulate climate specific design guidelines for reducing operational energy and improving thermal comfort in the residential buildings.

This paper discusses the baseline scenario of energy consumption of urban residential buildings in both composite and warm-humid climatic regions of India.

RESULTS AND ANALYSIS

A. Results of analysis of monthly electricity consumption data for sample flats in composite and warm-humid climates

Figure 4(a) and 4(b) shows EPI distribution graphs for residential units belonging to composite and warm-humid climates. The mean EPIs for residential flats in composite and warm-humid climate are calculated as 48 kWh/m^2.year and 43 kWh/m^2.year respectively.

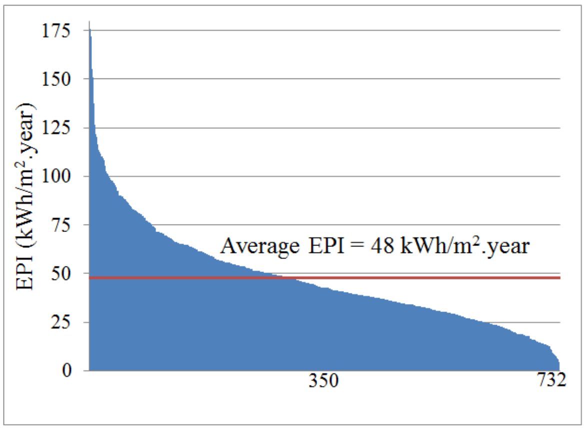
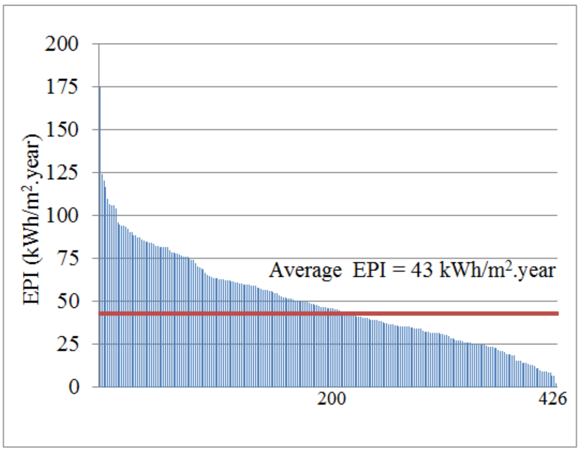


Figure 4(a) *EPI distribution of residential units in the composite climatic region*



4(b) *EPI distribution of residential units in the warm-humid climatic region*

Figure 5 shows average monthly energy consumption profile of two residential complexes, one each in composite (78 residential units) and warm-humid climates (243 residential units). The monthly electricity consumption for the residential complex in composite climate shows steep increase in energy consumption during the summer and monsoon months (May-August). This is attributed to the operation of comfort conditioning equipment. November can be considered as base month[4], when the need for comfort cooling or heating is minimum.

Monthly electricity consumption for the residential complex in warm-humid climate (Figure 5) shows a flatter profile during April to November, with peak appearing during the June and July months. This is due to extended warm and humid seasons, when comfort conditioning is required. December and January can be considered as base month when the requirement for comfort cooling or heating is minimum.

EPI range distribution for both composite and warm-humid climate (Figure 6(a) & 6(b)) shows that 16% of the residential units in the composite climate and 22% in the warm-humid climate have a high EPI of more than 70 kWh/m^2.year.

[4] "Base month" is the month during which there is almost no comfort cooling or heating requirements in the climatic region. During this time the energy consumption will be from refrigerator, lighting, washing machine, electric geysers, kitchen appliances, TV, computers, etc.

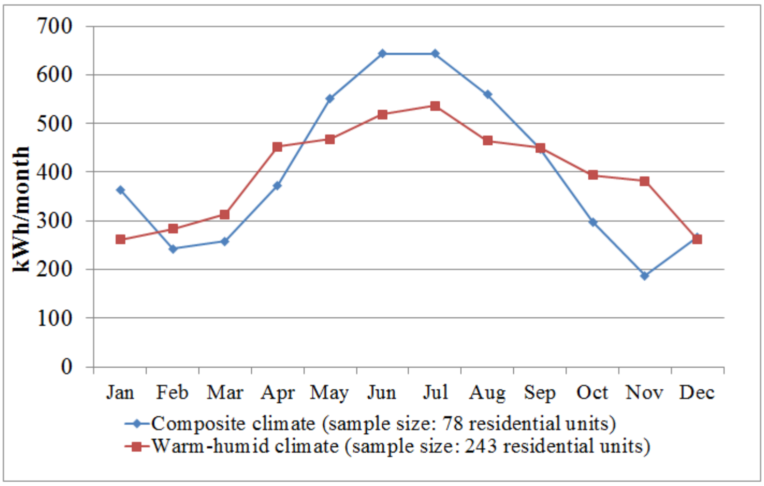


Figure 5 *Average monthly energy consumption profiles of two residential complexes in composite and warm-humid climates*

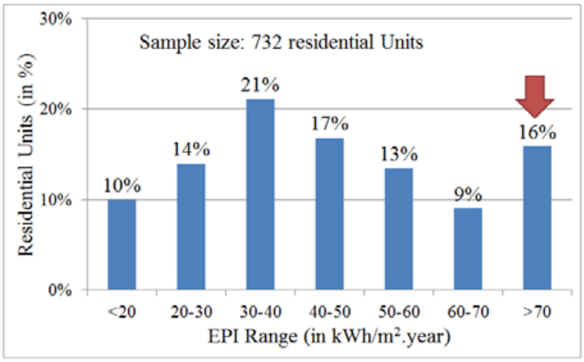


Figure 6(a) *EPI range distribution for residential units in composite climate*

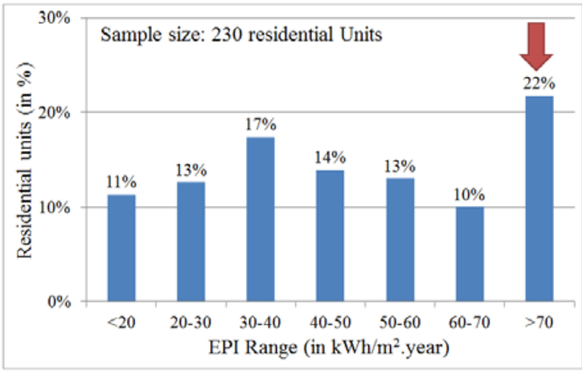
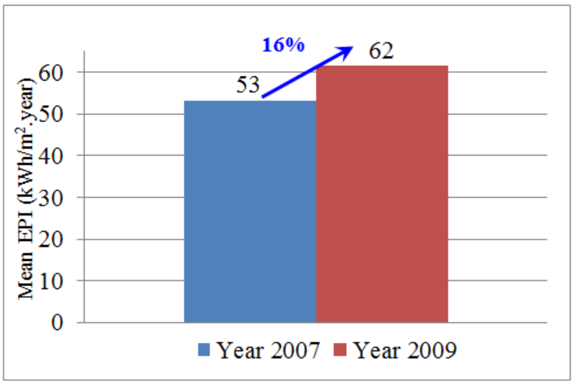


Figure 6(b) *EPI range distribution for residential units in warm-humid climate*

Time series energy consumption data for year 2007 and 2009 was collected for one of the residential complexes (78 residential units) in Delhi. Figure 7 shows that there is an increase in the average EPI of the complex by 16% in the year 2009 compared to 2007. This increase in average EPI is primarily attributed to the increase in energy consumption (by 20%) during the summer and monsoon periods (April to September). This reflects higher ownership and use of air-conditioning equipments with the increase in disposable income and availability of easy financing options and an aspiration for higher comfort.



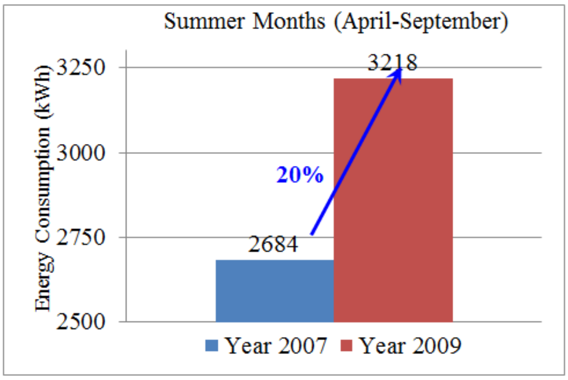
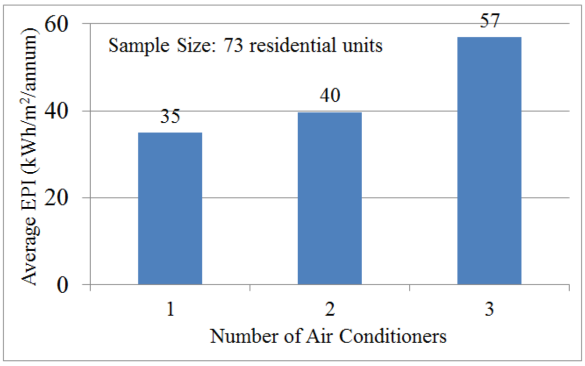


Figure 7 *Time series plot of a residential complex in Delhi*

7(a) *Mean EPI*

7(b) *Cumulative energy consumption per flat for summer and monsoon months (April- September)*

Figure 8(a) & 9(b) show that there is an increase in average EPI of residential units with the increase in ownership of number of air-conditioners in both composite and warm-humid climates respectively. There is an overall trend of increase in number of residential units with higher EPI.



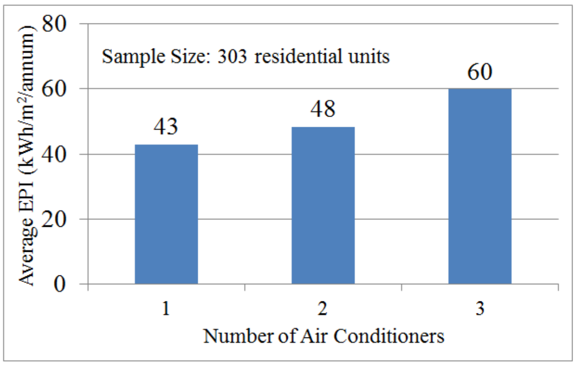


Figure 8(a) *Distribution of average EPI with respect to air conditioners ownership for residential units in composite climate*

8(b) *Distribution of average EPI with respect to air conditioners ownership for residential units in warm-humid climate*

B. Results of detailed energy monitoring in three flats of the composite climate

Analysis of energy consumption in 3 flats in the composite climate: a) Flat A having a below average EPI (in the range of 30 to 40) b) Flat B having an above average EPI (in the range of 60 to70) , and c) Flat C having high EPI (> 70EPI) is presented below:

Figure 9 shows monthly energy consumption and monitored energy consumption for comfort conditioning equipment for Flat A in Delhi. This flat used convective ceiling fans from mid-March to mid-October, 2 evaporative desert coolers were used from April to June and 2 air conditioners were used from June to July. The EPI of this flat was 35 kWh/m^2.year. Monitored data shows that almost 33% of the annual energy consumption is attributed to operation of comfort space conditioning equipment. Balance, 67% of the electricity (referred in this paper as base energy consumption i.e. energy used for purposes other than comfort cooling) is used for refrigerator, lighting, washing machine, electric geysers, kitchen appliances, TV, computers, etc.

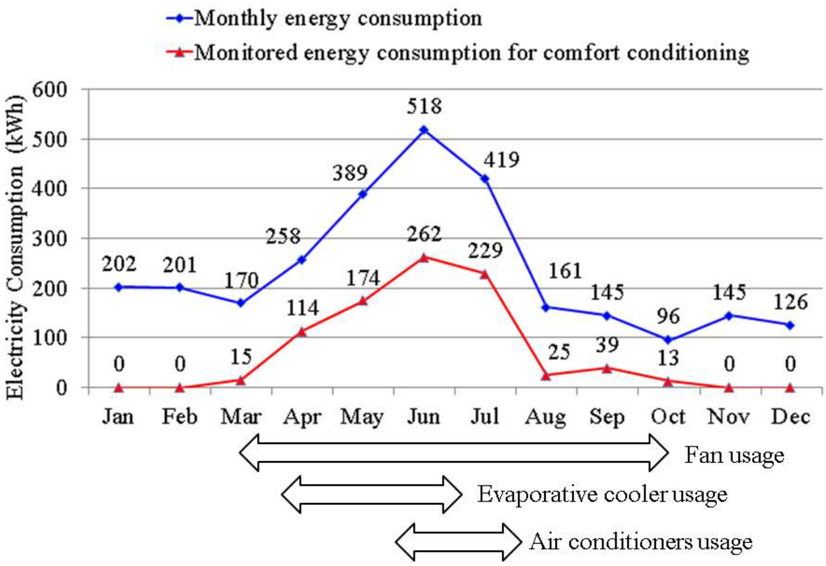


Figure 9 *Monthly energy consumption profiles for below average EPI in composite climate*

Figure 10 shows monthly energy consumption of two more residential units in the same residential complex. Residence-B uses 2 air-conditioners predominantly for comfort cooling and have an EPI of 65 kWh/m^2.year (~1.8 times compared to Residence-A). Residence-C with 4 air conditioners have an EPI of 117 kWh/m^2.year (~3.3 times compared to Residence-A). If energy consumption during February is considered as base energy consumption[5] for Residence B and Residence C, then the contribution of energy consumption for comfort space conditioning can be as high as 38% for Residence B and 65% for Residence-C.

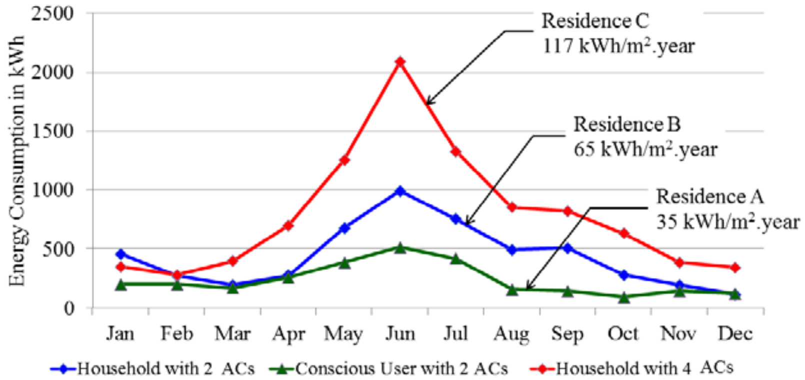


***Figure 10** Monthly energy consumption profiles of three residential units in composite climate*

CONCLUSIONS

a) The mean EPIs for sample residential flats of 2-3 bedrooms in composite (732 flats) and warm-humid climate (426 flats) for the year 2009 are calculated as 48 kWh/m^2.year and 43 kWh/m^2.year respectively

b) Energy consumption for comfort cooling is a significant part of the electricity consumption. Detailed analysis of energy consumption in three sample flats shows that the contribution of energy consumption for comfort space conditioning, increases with the increase in EPI (and increased usage of air-conditioners) and for the three flats was estimated to vary between 33% to 65% of the total energy consumption.

c) Analysis of time-series data for one residential complex for 2007 and 2009 shows 16% increase in average EPI, which indicates towards the trend of increase in energy consumption in the urban residential buildings d) Detailed energy consumption monitoring of a flat, which utilizes a combination of fans, evaporative coolers and ACs for cooling, shows potential of large energy savings by appropriate and energy-efficient use of comfort cooling appliances.

With bulk of the construction in building sector bound to happen in housing sector in the next two decades, there is an urgent necessity for guidelines for designers to effectively integrate the potential strategies for reducing energy consumption and for augmenting thermal comfort as well as guidelines for residents to use energy efficiently for space cooling.

ACKNOWLEDGEMENT

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[5] Base energy consumption is the energy consumption excluding the comfort space conditioning. This also excludes energy consumption for space heating.

Session 2C : User behavior, thermal comfort & energy performance

PLEA2014: Day 1, Tuesday, December 16
14:10 - 15:50, Grace - Knowledge Consortium of Gujarat

Cool spots in hot climates: a means to achieve pedestrian comfort in hot climates

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ABSTRACT

With the advent of automobiles, an increasing number of emerging cities are being planned for motorists. Ironically, motorists are least affected by harsh climate or distance. Planning is essentially required for pedestrians to traverse in the shortest possible routes with a pleasurable thermal comfort experience. Defining pedestrian comfort is complex, as it depends directly on dynamic climatic factors and also on the physiological and psychological factors. The current standards for outdoor comfort are based on static models which do not take into account the variability of climatic factors in the urban scenario and its impact on physiological factors with time. This paper focuses on understanding thermal comfort of pedestrians through literature and fieldwork to draw comfort limits and find the most influential factors that affect pedestrian comfort in hot climates. The research is carried out in the city of Sharjah, in UAE which experiences hot desert climate. The three factors that were identified to be the most influential for pedestrian comfort in Sharjah were – providing shade, enhancing wind movement and reducing mean radiant temperature. This paper also explores a design solution – 'cool spots' incorporating these factors in a way that best suits the urban context of Sharjah.

INTRODUCTION

UAE is a country that overturned the sands of the desert to become one of the most booming economies of West Asia. This resulted in rapid urbanization, and despite harsh climate, the urban centers developed without much consideration to these factors. Wide glass-faced urban canyons resulted in an urban fabric hostile to pedestrians. The problem faced by the pedestrians in UAE is that there is too much sun and too little shade.

Designing for pedestrian comfort in hot climates like UAE requires one to understand the climate, comfort limits and thermal adaptation of a pedestrian in the specific context. There are a number of thermal comfort assessment methods that have been developed. Some of the commonly used ones for outdoors are steady-state models like Predicted Mean Vote Index (PMV) or Predicted Percentage Dissatisfied Index (PPD) (Fanger,1982), Index of Thermal Stress (ITS) (Givoni, 1976) and Physiological Equivalent Temperature (PET) (Mayer & Hoppe,1987). The problem with these steady-state models is that they cannot account for the dynamic thermal adaptation of humans (Chen & Ng 2011).

Hence, in this paper, comfort limits are identified through literature studies and a series of experimental fieldwork in Sharjah, which helps confirm these limits. The cool spot is designed using these limits. For the purpose of evaluation of the conditions in the cool spot, PET is used, which gives an understanding of the difference in the felt temperature inside and outside the cool spot.

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FACTORS AFFECTING PEDESTRIAN COMFORT

The three factors that influence pedestrian comfort are environmental, physiological and psychological. The environmental factors depend on parameters of air temperature; air movement; radiation and humidity. Physiological factors depend on heat balance of the body, which is largely influenced by metabolic rates, physical activity and the type of clothing. Psychological factors depend on nature of space and usage, seasonal expectation and cultural and regional expectations.

This paper deals with pedestrian comfort in an urban context during hot periods. Hence, it addresses factors and limits in the light of reducing heat gains or enhancing cooling.

CLIMATE OF SHARJAH

Figure 1 shows a graphical representation of the monthly average temperatures in Sharjah (25.33^0N and 55.43^0E). The weather data is obtained from the Meteonorm global meteorological database (version 6.1) which represents a ten year average of the data files. Based on the monthly variations of Dry Bulb Temperature (DBT) of Sharjah, the annual cycle can be divided into three distinct periods – a four month period of mild weather (December to March inclusive), a warm period (November and April) and a hot period (May to October inclusive) (Yannas 2008).

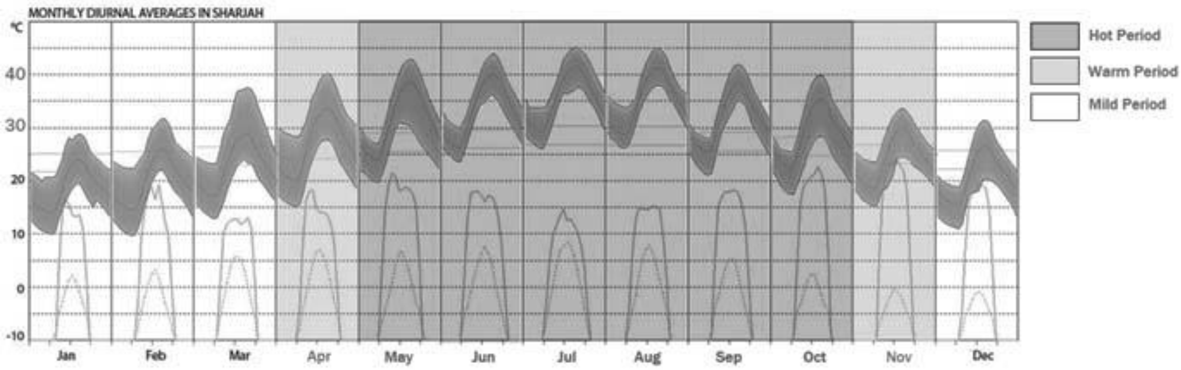

Figure 1 *Graphical representation of the monthly average temperatures.*

COMFORT LIMITS

In outdoor spaces, the aim is to provide tolerable thermal conditions to prolong the exposure time of the pedestrians (Tahbaz, 2010) rather than trying to achieve ideal thermal comfort. Hence it is significant to study the varying comfort limits for pedestrians in a particular climate.

Comfort Limits based on Environmental Factors

Figure 2 (**a)** shows the bioclimatic chart plotted for a clo value of 0.4 and 1.3 Met which indicates summer clothing and sedentary activity (like slow walking) respectively. The cluster of dots in the chart represents the DBT and Relative Humidity (RH) (source Meteonorm 6.1) values for all the days throughout the year. The chart is based on the limits described by Arens, Gonzalez and Berglund (1986) and assumes that air temperature is equal to the mean radiant temperature. The measure of comfort used to determine boundaries of the chart is skin wettedness (fraction of skin covered by sweat).

Comfort Limits of Air Temperature: Up to DBT 25^0C in **Figure 2(a)** the pedestrians are comfortable without an external shade. From DBT 25^0C to 32^0C pedestrians are comfortable underneath a shade and still conditions of air. The boundaries of comfort limit can be extended up to 39^0C DBT-underneath shade and 2m/s wind speed. This limit conforms to the findings of the fieldwork survey conducted by Thappar and Yannas (2008) in Dubai (25.14^0N, 55.17^0E) (a neighbor city that shares similar climate with Sharjah) where ambient temperatures close to 40^0C in shade, with wind velocities of 2m/s were perceived as acceptable conditions.

Comfort Limits of Air Velocity: The comfort boundary can be stretched to 42^0C with an air velocity of 4 m/s and further to 44^0C up to a mean maximum of 6m/s (Arens et al. 1986), provided the turbulence is low. Above 6m/s, the mechanical effects of wind counterbalance any of its positive effects on comfort. Air velocity at high temperatures has opposite influences on comfort. It increases the evaporative capacity of the air, and hence the cooling impact on the skin, but also causes higher convective exchange that warms the body Givoni (1976). Hence, there is an optimum velocity of air movement that produces the highest cooling. This optimum velocity depends on temperature, humidity, metabolic activity and clothing. Based on Givoni's (1976, p 66 - 67) method, at a temperature of 40^{0}C and vapour pressure 30mmHg, for a pedestrian whose metabolic activity is 2.4 – 3 Met (walking at 4km/hr), the optimum velocity averages between 2.9 to 4.0m/s. For metabolic activities at 1.2 – 1.4 Met under the same conditions, the optimum velocities average between 1.2 -2.0m/s

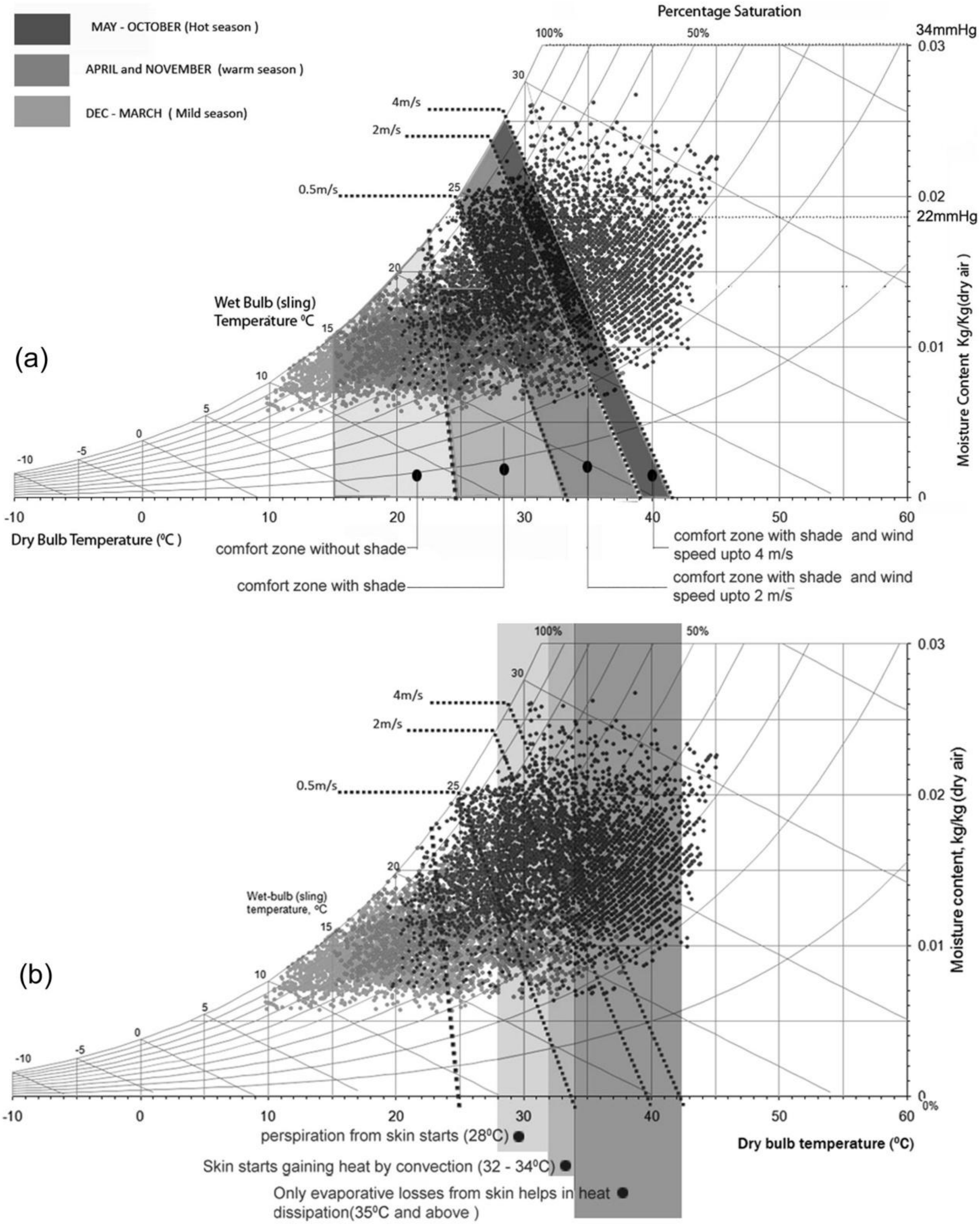

***Figure 2** (a) Bioclimatic chart based on environmental factors. (b) Bioclimatic chart based on physiological factors.*

Comfort Limits of Humidity: Vapour pressure below 5mmHg is likely to cause respiratory discomfort (Erell, Pearlmutter&Williamson, 2011). Vapour pressure of air above 37mmHg corresponds to the vapour pressure of skin and hence indicates the highest level of discomfort. Vapour pressure of 22mmHg corresponds to a wet bulb temperature of 24^{0}C (at ambient temperature of 34^{0}C), which Givoni (1998) suggests as the upper limit for the application of direct evaporative cooling of DBT.

Comfort Limits: Bioclimatic Chart based on Physiological Factors

Figure 2(b) defines the boundaries of extended comfort achieved by the human body through physiological responses to cooling. Up to about 25^0C, the heat balance of the body is maintained by the minimum thermoregulatory processes and heat exchanges required. This takes place mainly through convection and radiation. At 28^0C, the body starts perspiring and above 28^0C, true sweating occurs wherein water is exuded to the skin (Oke 1987). At about 32^0C – 34^0C, convective losses turn into convective gains as the gradient between skin and ambient temperature becomes nil. At an ambient temperature of 35^0C and above, only evaporative losses from skin help in heat dissipation. The chart clearly indicates that during a large span of the hot period, evaporative loss is the only means of heat regulation for the body. The rate of evaporative losses depends on body to air, vapour pressure gradient and air velocity (Givoni 1976), hence making both these limits influential for pedestrian comfort.

FIELDWORK

The fieldwork was carried out to validate the theoretical understanding of the comfort limits described above and to identify the most influential factors of comfort in this context.

Outdoor comfort studies are usually conducted by questionnaire surveys, where subjects are interviewed. The limitation of this method as described by Ng E et al (2012) is that the thermal sensation of the subject is captured under relatively static climatic conditions. This fieldwork study introduces an experimental methodology - measuring the skin temperature of a pedestrian in a series of three experiments while in motion, hence giving an understanding of thermal stress experienced over time.

The fieldwork was conducted in Sharjah during the two hottest months – August to September, during the day to measure thermal stress in the worst case scenario. The thermal stress was weighed based on skin temperature relative to air temperature, as it is determined by the local equilibrium conditions of heat flow from the body core to the skin and the heat loss from the skin to the environment (Givoni 1976). Observation of skin wettedness and sweating were also noted at regular intervals. Instruments used for fieldwork were an anemometer for measuring wind speed, two hand held data loggers – one for measuring globe temperature and one for logging DBT and RH, and a temperature logger with a thermistor surface temperature probe to measure skin temperature.

Skin temperature measurements are usually taken at 16 points and their mean weighted average is the resultant, but in cases where the DBT is at 32^0C and above, the variation of temperature over the whole skin is less than 2^0C (Givoni 1976). For this reason, the skin temperature was approximated using temperature measurements on just one point on the body, that is, on the wrist of the subject.

Measurements of skin temperature, ambient air temperature and relative humidity were recorded simultaneously and spot measurements of wind speeds were taken. Notes based on observation and questioning were recorded to mark levels of discomfort through sweating. The recorded skin temperature corresponds to conditions stated by Givoni (1976) – skin temperature in comfortable conditions is 33^0C; at moderate heat conditions, 35^0C and during severe heat, it reaches 37^0C.

The test subject was a male, 58 years old with dark complexion and is a representative sample of the labour workforce in UAE, who are most likely to use outdoor spaces during the hottest periods of day.

Experiment 01 – Alternate walks in sun and shade

The walk was conducted during day time and the average temperatures recorded were 42^0C. Given the temperature and clear skies, the walk is not a leisure walk, rather a deterministic walk i.e. a walk for a necessary activity. In case of leisure walk, the discomfort expressed could be higher and at more frequent intervals than for a deterministic walk.

The walk spanned about an hour with a routine - 10 minutes walk in the sun (without any overhead gear) and 5 minutes rest in an air-conditioned/shaded zone. The candidate was given the choice of reducing or increasing either the exposure or the rest time based on the comfort levels.

Figure 3 shows the graph with the plotted skin temperature, ambient air temperature and RH measured during the walk. The shaded regions in the graph indicate the time span resting in shaded/air conditioned zone and the lighter regions indicate the time span walking while exposed to direct sunlight. The circled numbers mark the descriptive note of the conditions and the observations made. Few of the significant ones are **shown in Table 5**.

Table 5. Descriptive Note of Conditions and Observations Made During Experiment 01

	Description
1	The walk started from an air-conditioned indoors maintained at comfortable temperatures between 26^0C – 27^0C. The skin temperature measured was 33.3 ^{0}C which is consistent with Givoni's (1976) conditions of skin temperature.
3	Walking at medium pace (4km/hr) in the sun, air temperature recorded was 40^0C - 42^0C. The skin temperature increased from 35^0C to 38.6^0C in 9 minutes. Within 5 minutes, the skin was clammy and at the end of 9 minutes, the forehead was observed to be wet and the candidate expressed the need to be in a shaded/air-conditioned zone.
4	Stepping into an air-conditioned mall with an indoor temperature between 25^0C - 26^0C, the skin temperature dropped to 34.5^0C in 5 minutes. The forehead and body were dry within this time.
5	Resuming the experiment of walking in the sun, recorded air temperature is at 40 – 41^0C. The skin temperature increased to 38^0C in 4 minutes. The rate of sweating increased and the candidate expressed his forehead and back to be wet.
6	Walking in an enclosed, non air-conditioned market with ceiling fans (at 4m high); the air temperature and wind speed recorded was 35^0C, and 0.0 - 0.5m/s respectively. Though the skin temperature dropped to 36^0C in 3 minutes, the candidate expressed discomfort and the need to be outside the market at the end of 3 minutes. The ambient wind speed before walking into the market was measured at 1.1 -1.5 m/s which dropped inside the market. This could be the possible explanation for the candidate's discomfort.
7	Continuing the walk in the sun, at an air temperature of 41 – 42^0C., the skin temperature increased from 36^0C to 39^0C in 2 minutes and to 39.8^0C in the next 2 minutes. The candidate expressed high level of discomfort and it was observed that the clothing was completely wet with sweat.
8	Resuming a slow walk in the air-conditioned mall, air temperature was recorded to be 25-26^0C and the skin temperature dropped to 34^0C in 3 minutes.
9	Walking with the back facing the sun was claimed to be more comfortable than the other way round; recorded air temperature was 41-43^0C. The skin temperature reached 39^0C in 4 minutes with profuse sweating.
10	While seated and taking rest in the air-conditioned mall, recorded temperature was 25^0C.The skin temperature reached 33^0C in 9mins.

Observations and Conclusions: Starting from comfortable indoor conditions and walking at a pace of 4km/hr, a 10 minute exposure to direct sunlight can be considered the maximum acceptable before an air-conditioned resting zone is required to bring down the skin temperature to comfortable conditions. This distance, when calculated based on the above study is 667m. If these resting zones were to be replaced by shaded zones (or cool spots), the minimum distance of exposure to avoid thermal stress can be reduced to half, at approximately 300m for urban design considerations.

The time taken for the rise in the candidate's skin temperature is inversely co-related to his exposure in the sun. Hence, if a particular path has to designed with air-conditioned nodes, the distance between the nodes have to decrease incrementally to ensure that the skin temperature remains in the comfortable range.

This experiment also shows that in hot climates like Sharjah, skin wettedness influences thermal comfort in a shaded zone more than a decrease in 5^0C-6^0C in DBT. Hence, an increase in wind speed would be more beneficial in design application rather than a decrease in a few degrees of temperature.

The rise in skin temperature reduces considerably after it reaches 39^0C.

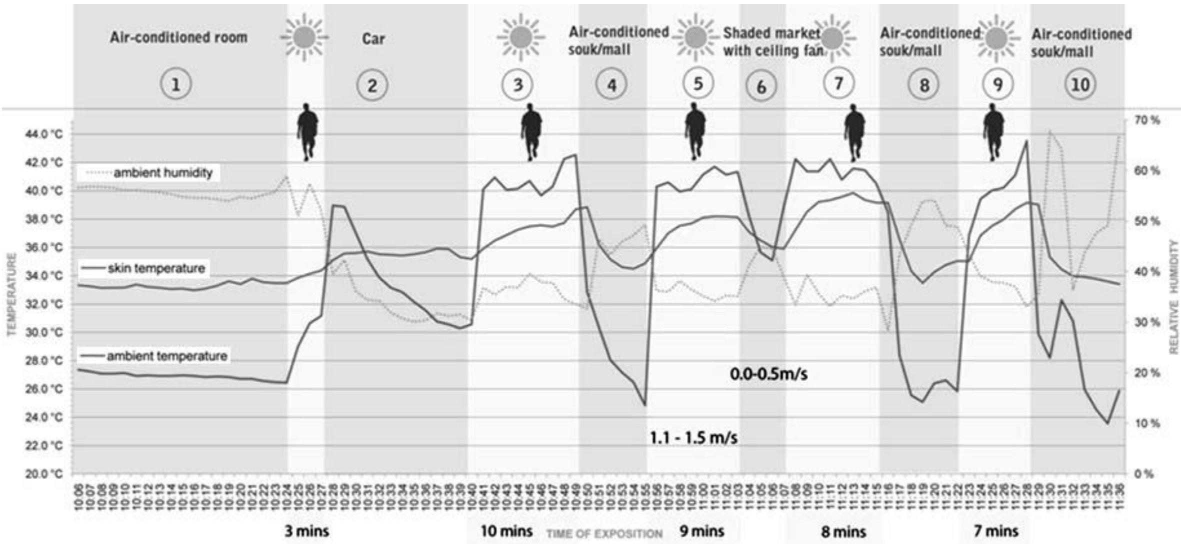

Figure 3 *Graph showing measured skin temperature, ambient DBT and RH during Experiment 01.*

Experiment 02 – Walk in Shade

In experiment 02, the candidate was asked to walk for 10 minutes in a shaded zone without any exposure to the sun. **Figure 4** shows the graph plotted with the measured skin temperature, ambient air temperature and relative humidity. The shaded region in the graph indicates the measurements taken when the candidate walked under the building shade for 10 minutes. The lighter region shows the measurements taken indoors.

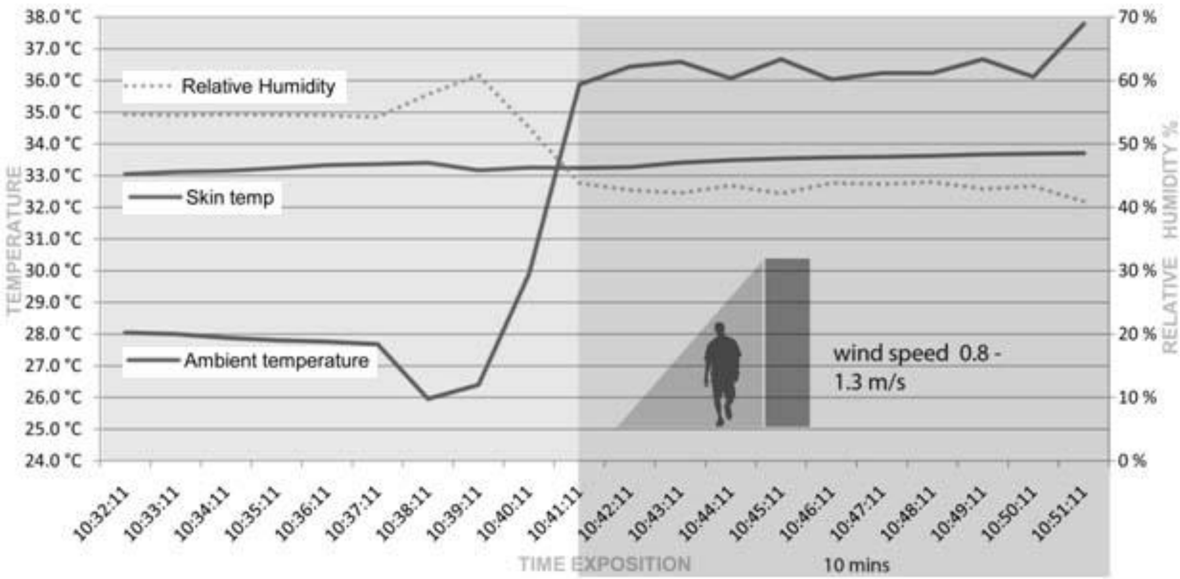

Figure 4 *Graph showing measured skin temperature, ambient DBT and RH during Experiment 02.*

Observations and Conclusions: As seen from the graph, though the ambient temperature increased from indoors to outdoors from 26^0C to about 36.4^0C, the skin temperature increased only slightly, from 33.2^0C to 33.6^0C. The measured wind speed was 0.8 -1.3 m/s and hence, the skin remained relatively dry.

Experiment 03 – Standing in sun

In continuation with experiment 01, the candidate was asked to stand in the sun for 10 minutes without any head gear. The wind speed was measured to be 2–2.5 m/s. This experiment was conducted to understand the effect of wind as a standalone factor to thermal stress. **Figure 5** shows the graph with measurements plotted during the experiment.

Observations and Conclusions: At ambient temperature of 40^0C - 43^0C, the skin temperature remained at an average 37.2^0C and reached a maximum of 37.6^0C unlike in experiment 01, where it rose to 39^0C. This could be due the effect of wind speed at 2-2.5 m/s that continuously enhanced the evaporation of the sweat, hence cooling the skin.

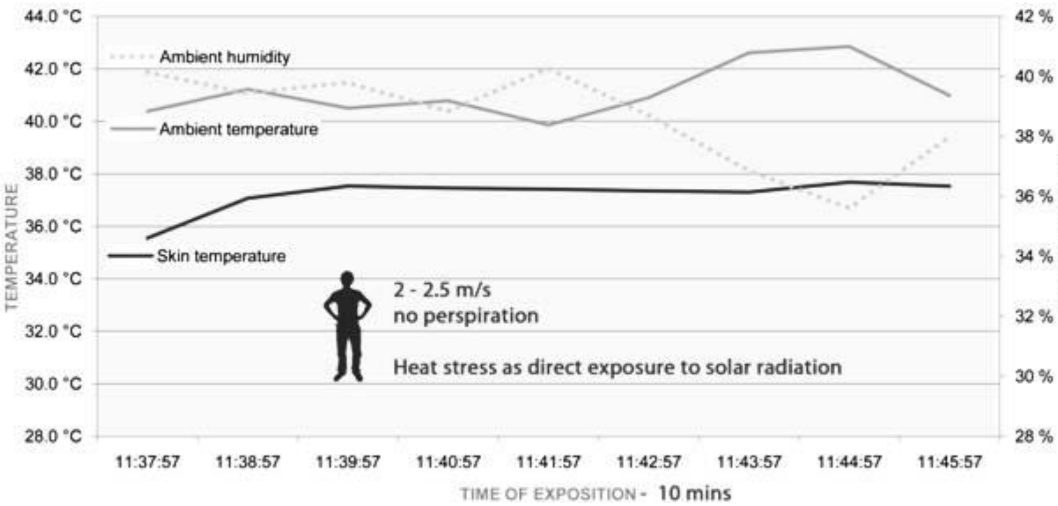

Figure 5 *Graph showing measured skin temperature, ambient DBT and RH during Experiment 03.*

DESIGN OF COOL SPOTS

The three factors that were identified through research and fieldwork to be the most influential in Sharjah for improving pedestrian comfort were providing shade – cut off all the solar radiation, enhancing wind movement – providing a minimum air movement of 2m/s and a maximum of 4m/s at pedestrian level and reducing mean radiant temperatures – maintaining immediate surrounding surfaces of a pedestrian close to air temperature. The design and concept of the cool spot is a direct synthesis of the three factors mentioned.

Among the five categories of fieldwork (1.Measuring surface temperature of common surfaces in the urban fabric, 2.Measuring conditions underneath different kind of shades, 3.Datalogging conditions underneath the Masdar cooling tower in Masdar city, Abu Dhabi, 4.Measuring thermal stress of a pedestrian and 5.Observing pedestrian activity in Sharjah) that contributed to the design of the cool spot, only one category – measuring thermal stress of a pedestrian has been explained in this paper.

The geometry of the cool spot is designed to allow for the wind to pass through it from any direction. Fans are integrated in the centre in case of no wind condition. The cool spot is designed so as to ensure the central space of diameter 3.2m remains shaded throughout. Materials used for cool spot do not heat up above the air temperature as shown in **Figure 6(a)**.

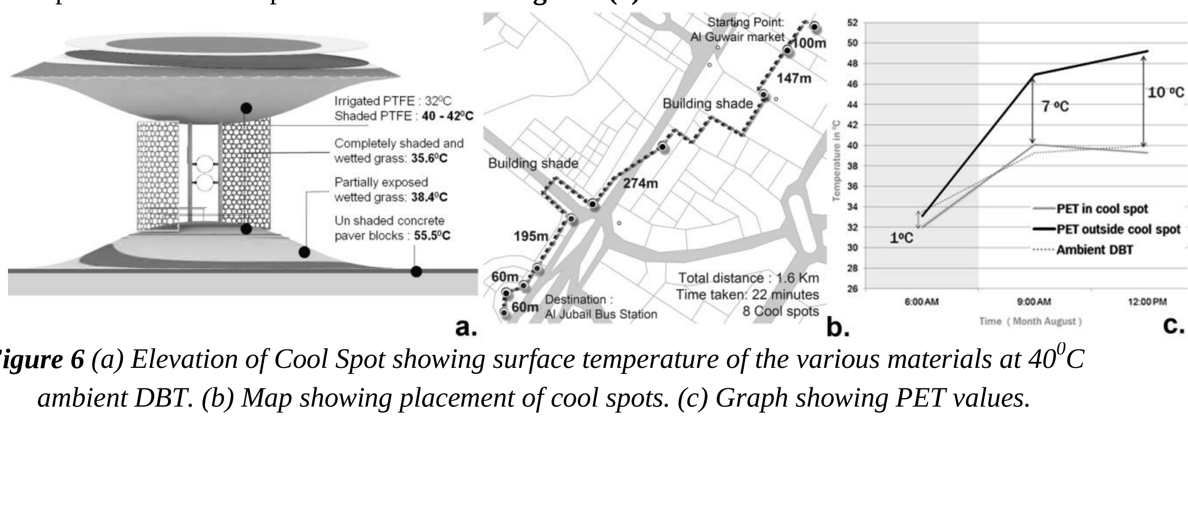

Figure 6 *(a) Elevation of Cool Spot showing surface temperature of the various materials at 40^0C ambient DBT. (b) Map showing placement of cool spots. (c) Graph showing PET values.*

The Physiologically Equivalent Temperature (PET) was calculated using RayMan version 1.2 inside and outside the cool spot for a typical day in August, shown in **Figure 6(c).** The results show that during the hottest time of the day, the felt temperature (PET) in the cool spot is 10^0C lesser than the outside temperature.

Figure 6(b) shows a map of a pedestrian route in Sharjah connecting a residential/commercial area to an intercity bus stand. This stretch of 1.6 km, with the introduction of cool spots at a minimum distance of 60m (to prevent the interference of the wind flow pattern between two cool spots) and maximum distance of 300m ensures a pedestrian experience with reduced thermal stress.

CONCLUSION

Designing for pedestrian comfort requires understanding the climate and the comfort limits. Initial stages of this research (not mentioned in this paper) looked at design strategies to reduce air temperature. This was overruled as fieldwork in Sharjah revealed that air movement had more influence on comfort than a few degrees decrease in temperature.

Through literature review and fieldwork it was understood that, during the hot period in Sharjah temperatures of 40^0C – 42^0C were considered acceptable, provided the pedestrian is in complete shade and there is a minimum wind speed of 2m/s and maximum 4m/s. Although the fieldwork conducted in this study used only one subject, it can be extended to larger group to arrive at a more comprehensive results. Such a study could be conducted using a similar methodology as outlined in this work.

This paper also proposes a design solution - Cool Spots - to achieve pedestrian comfort in Sharjah. The design of the cool spots is based on the three factors – provide shade, enhance wind movement and reduce mean radiant temperatures close to air temperature. The concept of a cool spot as an urban furniture is specific to Sharjah/UAE as it is a response to both the cultural as well as the climatic expectations of the pedestrians there. It was observed that people felt comfortable underneath a tree canopy, especially under the dense and wide one of a banyan tree. Given the desert climate in Sharjah, trees like the banyan are not a common sight. Cool spots are intended to serve the function of such a canopy, but unlike trees that reduce the wind speed underneath them, cool spots enhance it. The felt temperature (PET) within the cool spot was analysed (using RayMan 1.2) to be 10^0C lesser than the outside temperature at peak conditions (noon) during one of the hottest month (August) in Sharjah.

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The Effect of Natural Ventilation and Daylighting on Occupants' Health in Malaysian Urban Housing

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ABSTRACT

Terraced houses have been rapidly constructed in Malaysia since 1960's and account for 44% of the existing urban housings. The spatial characteristics of the houses have been remained the same for decades although these houses have very constrained use of natural ventilation and daylighting due to deep planning. This kind of design causes indoor thermal and visual discomforts due to gloomy indoor spaces, low air change rate and poor indoor air quality. As studies proved that indoor environmental stressor can produce negative stress on occupants' health, the effect of natural ventilation and daylighting on occupants' comfort and health in the terraced houses was investigated. Case study of 80 terraced houses in Johor Bahru, Malaysia was conducted to identify the critical comfort and health issues due to natural ventilation and daylighting. The relationships between occupants' comfort, behavior and health were studied through questionnaire survey. The findings demonstrated significant linear relationships between indoor comfort and health. However, occupants' behavior did not give significant impact on comfort and health. Besides, the effects of natural ventilation and daylighting performances on specific health issues were also studied. The findings concluded that the by-law requirement of 5% window-to-floor ratio for natural ventilation is inadequate for occupants' comfort and health, thus further review is needed. Proper consideration of natural ventilation and daylighting design strategies in terraced house is essential as it determines how the occupants can manage the indoor environment to achieve comfortable and healthy living environment.

INTRODUCTION

Since 50 years ago terraced houses have been rapidly constructed in Malaysia due to the increasing demands for urban housing. This housing typology accounts for more than 40% of the existing housing stocks in the urban areas (Malaysia Department of Statistic, 2000). The origin of this housing typology is adopted from the British terraced house design which is also known as "row house". This type of house has relatively narrow and deep plan with limited fenestration at the front and rear facades. The typical width of Malaysian terraced house ranges from 18 ft. (5400 mm) to 25 ft. (7500 mm); while the length is 65 ft. (19500 mm) to 80 ft. (24000 mm). The housing layout is usually planned repetitively and monotonously in rows of rectangular lots. The boundaries of the houses are defined by perimeter chain-linked fences or bricks walls (Hashim and Rahim, 2008; Omar et al., 2010).

The typical spatial characteristics of the terraced houses in Malaysia have been remained the same for decades (Omar et al., 2010). Most terraced houses have combined living and dining hall, minimum three bedrooms, two or three bathrooms, a kitchen at the back and a car porch at the front. For double-storey terraced house, the space under the staircase is commonly used as storage area. On the first floor, master bedroom with an attached bathroom is usually located at the front; while two other bedrooms which share a bathroom sitauted at the back. Besides, some of the terraced houses have a small family hall placed in the center to connect all the bedrooms with the staircase. Examples of typical Malaysian terraced house design and layout are shown in Figure 1.

Figure 1 Example of typical terraced houses in Malaysia: (a) Frontage, (b) Layout plans

The roofs are the major building envelopes of terraced houses that are exposed directly to solar radiation. Hence, proper insulations are needed to reduce the heat conduction from the roof into the indoor spaces. Despite global illuminance as high as 130 klx, the openings on the front and back façades and the roofs are the very limited sources for daylighting. The openings also allow unwanted solar radiation heat gain. Besides, natural ventilation in terraced houses is constrained by the small window-to-floor ratio (WFR). Moreover, tropical climate has high air temperatures, high relative humidity and very low wind speeds (Agung and Mohd Hamdan, 2006; Lim et al., 2012; Lim, 2013).

In Malaysia, some research works had been conducted in the terraced houses in tropical climate. Sadafi et al. (2011) investigated the thermal effects of internal courtyard in a tropical terraced house in Malaysia. The findings showed that internal courtyard allows better natural ventilation but increases the radiation heat gain. Hence, efficient openings and shading devices are needed in order to improve the thermal conditions of the courtyard's surrounding spaces. Kubota et al. (2009) examined the effects of night ventilation technique on indoor thermal environment for terrace houses in Malaysia. The findings concluded that the indoor humidity control during the daytime such as by dehumidification would be needed when the night ventilation technique is applied to Malaysian terraced houses. Otherwise, full-day ventilation would be a better option compared with night ventilation.

Zakaria (2007) studied sustainable housing for residential-industrial neighborhoods in Malaysia by looking into several indoor environmental quality (IEQ) aspects. Questionnaire surveys, physical measurements and interviews were conducted for housing area in Pasir Gudang, Johor, Malaysia. Nevertheless, the focus of the study was on the IEQ especially air quality due to pollution from industries. The researcher did not emphasize the impact of other IEQ aspects on occupants' health.

Most of the previous research on terraced houses in Malaysia was limited to indoor environmental performance. However, studies have shown that indoor environments, including work and living spaces, have major impact on occupants' well-being (Bluyssen et al. 2011; Choi et al., 2012; Todorovic and Kim, 2012). Environmental stressor such as discomfort air temperature, poor air quality and inadequate lighting can produce negative stress. Thereby, this paper studies the impacts of natural ventilation and daylighting on occupants' comfort and health in existing Malaysian typical terraced houses.

METHOD

Case study of indoor environment, occupants' perceived comfort and health in Malaysian terraced houses was conducted. Questionnaire method was employed to conduct survey in 10 different terraced housing estates in Johor Bahru, Malaysia during the months of July to September in year 2013. All the selected terraced housing estates were located within the neighbourhood of Skudai, Johor Bahru, Malaysia. Random purposeful sampling method was employed in order to cover various types of terraced houses including intermediate, corner and end lot units. The total number of study cases was 80 houses. The summaries of respondents according to house types are as shown in Table 1.

Table 1. Summary of study cases according to housing type

Type	No. of Storey	No. of House(s)	Percentage (%)	
Intermediate Unit	1	29	36.3	81.3
	2	35	43.7	
	3	1	1.3	
Corner Unit	1	8	10.0	13.7
	2	3	3.7	
End Unit	1	3	3.7	5.0
	2	1	1.3	
	Total	**80**	**100.0**	**100.0**

The design of the questionnaire was divided into 4 major sections. Section 1 was intended to evaluate the effect of natural ventilation on indoor temperature and air quality. Section 2 was to obtain feedbacks from occupants regarding to the use of daylighting for task performance and visual comfort. Section 3 investigated the behavior of the occupants to use and control the natural ventilation and daylighting. Section 4 aimed to evaluate the occupants' psychological and physical health. All the questions were using 1 (lowest) to 5 (highest) scales.

The data collected were analyzed using statistic methods. First of all, the means of each question in Section 1, 2 and 4 were computed in order to identify the most critical indoor comfort and health issues. Then, the correlations between Natural Ventilation (Section 1) and Health (Section 4), Daylighting (Section 2) and Health (Section 4), Natural Ventilation (Section 1) and Behavior (Section 3), Daylighting (Section 2) and Behavior (Section 3) as well as Behavior (Section 3) and Health (Section 4) were analyzed. Spearman's rho correlation was employed for this analysis since the data was qualitative in nature thus fall under the category of non-parametric test. This correlation tests were important to understand the significant relationships among the variables.

Finally, more detailed analysis was conducted by investigating the correlation for specific questions from Section 1 and 2 against specific questions from Section 3 and 4. These questions were selected for analysis due to the relevancy such as indoor temperature comfort against behavior of controlling air-conditioning and natural ventilation. Spearman's rho correlation was employed for this analysis to look into the factors of indoor comfort which influenced the occupants' behavior and health.

RESULT AND ANALYSIS

Figure 2 shows the 5 most critical comfort issues and the 5 most critical health issues accoding to the respondents' opinions. The lowest score for comfort issues was discomfort indoor air temperature during noon time with mean 2.69. Meanwhile, the second lowest score was air movement in other bedrooms with mean 2.78. Indoor temperature and air movement were the major indoor comfort issues. Only 1 of the issues was related to daylighting due to insufficient brightness in toilet.

On the other hand, the mean scores for health issues ranged higher than the mean scores for indoor environmental issues. Among the 5 lowest scores, 2 of them were related to psychological health that influenced their minds and emotions. Among all the physical health issues, lethargy or tiredness obtained the lowest score. This issue can be related to poor ventilation and air quality as well as insufficient daylighting.

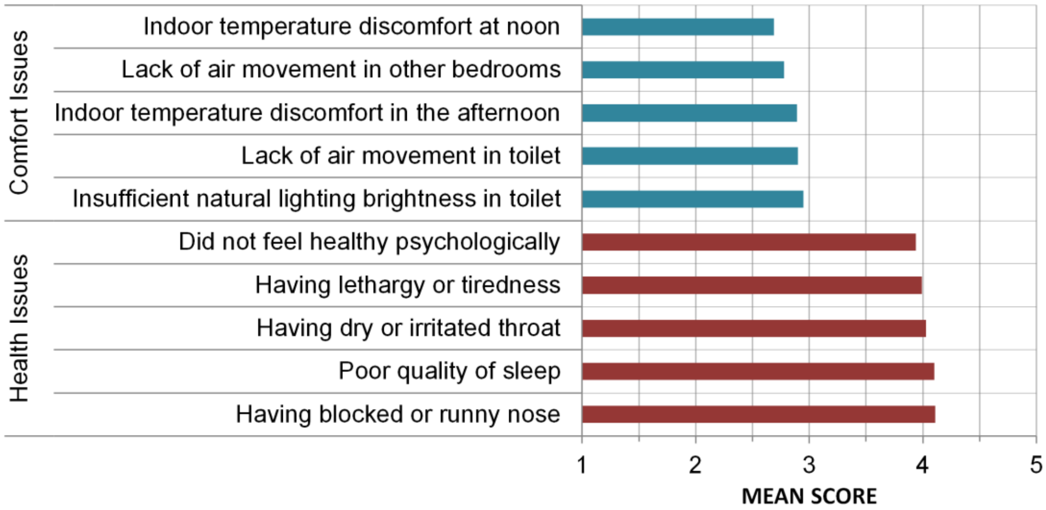

Figure 2 Critical comfort and health issues with the lowest mean scores

Spearman's rho correlation tests were used to identify the strength of the linear relationship between 2 variables. Table 2 shows the correlation among Sections 1 to 4. The analysis showed positive linear relationship between Natural Ventilation (Section 1) and Occupants' Health (Section 4), Daylighting (Section 2) and Occupants' Health (Section 4), as well as Daylighting (Section 2) and Occupants' Behaviour (Sectoion 3). The value of 'sig. (2-tailed)' (0.000) was less than the predetermined alpha value (0.01/2 = 0.025), thus the stated null hypothesis was rejected. There existed adequate evidence to show that there was significant positives linear relationship between these variables. This conclusion was made at the significance level of 0.01.

Table 2. Correlations among Section 1 to 4

			SECTION 3 (Occupants' Behaviour)	**SECTION 4 (Occupants' Health)**
Spearman's rho	**SECTION 1 (Natural Ventilation)**	Correlation Coefficient	0.198	0.549**
		Sig. (2-tailed)	0.079	0.000
	SECTION 2 (Daylighting)	Correlation Coefficient	0.474**	0.506**
		Sig. (2-tailed)	0.000	0.000
	SECTION 3 (Occupants' Behavior)	Correlation Coefficient	-	0.199
		Sig. (2-tailed)	-	0.077

**. Correlation is significant at the 0.01 level (2-tailed).

There was a positive linear relationship between Natural Ventilation (Section 1) and Occupants' Behavior (Section 3). The value of 'sig. (2-tailed)' (0.079) was more than the predetermined alpha value (0.05/2 = 0.025), thus the stated null hypothesis was accepted. There existed not adequate evidence to show that there was significant positives linear relationship between these 2 variables. For the correlation between Occupants' Behavior (Section 3) and Occupants' Health (Section 4), there was a positive linear relationship between these 2 variables. The value of 'sig. (2-tailed)' (0.077) was more than the predetermined alpha value (0.05/2 = 0.025), thus the stated null hypothesis was accepted. There existed not adequate evidence to show that there was significant positives linear relationship.

Table 3. Correlation Sig. (2-tailed) for selected questions in Section 1 (Natural Ventilation)

			Section 3 – Occupants' Behaviour			Section 4 – Occupants' Health								
						Psychological Health			Q5. Physical Health / Symptoms					
			Q1. Switch on A/C	Q2. Open windows for ventilation during day time	Q3. Open windows for ventilation during night time	Q1. Feel healthy	Q2. Able to sleep well	Q3. Able to concentrate well	b) Blocked / runny nose	c) Dry / irritated throat	d) Chest tightness	e) Dry / irritated skin	f) Headache	g) Lethargy / Tiredness
Section 1 – Natural Ventilation	Q1. Indoor Tempera-ture during:	a. Morning	0.473	0.010 **				0.001 **						
		b. Noon	0.879	0.589		0.009 **		0.879						
		c. Afternoon	0.260	0.690		0.010 **		0.008 **						
		d. Night	0.559		0.446	0.027 *	0.000 **	0.006 **						
	Q2. Air Moveme nt in:	a. Living Hall		0.000 **		0.000 **			0.000 **		0.000 **		0.001 **	0.000 **
		b. Dining Hall				0.000 **			0.215		0.022 *		0.123	0.013 *
		c. Kitchen		0.104										
		d. Master Bedroom		0.484		0.378			0.549		0.049 *		0.078	0.157
		e. Other Bedroom		0.995		0.146			0.583		0.121		0.016 *	0.030 *
		f. Toilet		0.912		0.059								
	Q3. Stuffy air			0.247		0.001 **			0.051	0.063	0.004 **	0.355	0.014 **	0.000 **
	Q4. Bad smell			0.077		0.029 *								

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlation Sig. (2-tailed) for selected questions in Section 2 (Daylighting)

			Section 3 – Occupants' Behaviour			Section 4 – Occupants' Health						
						Psychological Health				Q5. Physical Health / Symptoms		
			Q4. Switch on electric lighting during day time	Q5. Open window curtain / blinds for daylight	Q6. Enjoy view through windows	Q1. Feel healthy	Q2. Sleep well	Q3. Concentrate well	Q4. Do not feel depression / anxiety	a. Dry eye / Watering eyes (Epiphora)	f. Headache	g. Lethargy / Tiredness
Section 2 - Daylighting	Q1. Sufficient daylight brightness in:	a. Living Hall		0.000 **		0.000 **			0.138	0.012 *	0.067	0.000 **
		c. Kitchen		0.000 **								
		d. Master Bedroom		0.224		0.001 **			0.001 **	0.077	0.000 **	0.000 **
		e. Other Bedroom		0.021 *		0.006 **			0.002 **	0.442	0.023 *	0.001 **
		f. Toilet		0.559		0.049 *						
	Q2. Glare / contrast when windows are unshaded			0.385	0.299			0.667			0.052	
	Q3. Using daylight to do:	a. Reading	0.000 **					0.000 **				
		b. Writing	0.000 **					0.000 **				
		c. Computer work	0.000* *					0.000* *				
		d. Leisure	0.022 *					0.000 **				
		e. Cooking	0.002 **					0.001 **				

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3 presents Spearman's rho correlation analysis results for the selected questions regarding to natural ventilation, occupants' behavior and occupants' health. The results showed that indoor temperature did not give significant impact on occupants' behavior except "indoor temperature in the morning" against "opening windows for ventilation during daytime". However, indoor temperature yielded significant linear relationship with occupants' psychological health which includes "feeling healthy", "able to sleep well" and "able to concentrate well". The value of 'sig. (2-tailed)' was less than the predetermined alpha value (0.01/2 or 0.05/2) except "indoor temperature during noon time" against "able to concentrate well".

From the correlation analysis, the results demonstrated that air movement gave substantial impact on occupants' physical health. For instance, "air movement in living hall" yielded significant positive linear relationship with health symptoms like "blocked / runny nose", "chest tightness", "headache" and "lethargy / tiredness". On the other hand, there were significant positive linear relationship between "stuffy air" and health symptoms such as "chest tightness", "headache" and "lethargy / tiredness". The values of 'sig. (2-tailed)' for these correlations were less than the predetermined alpha value (0.01/2 = 0.025), thus the stated null hypothesis was rejected. This conclusion was made at the significance level of 0.01.

Spearman's rho correlation analysis results for the selected questions related to daylighting, occupants' behavior and occupants' health are as stated in Table 4. The results indicated that "sufficient daylight brightness" had significant positive linear relationship with "feeling healthy". Besides, there were also significant relationship between "sufficient daylight brightness" and physical health symptoms such as "epiphora", "headache" and "lethargy / tiredness".

Glare or contrast from unshaded windows did not give significant relationship to occupants' behavior and occupants' health. On the contrary, sufficient daylight to perform tasks such as reading, writing, computer work, leisure and cooking directly influenced occupants' behavior to control electric lighting during day time. Apart from that, "using daylight" for task performance yielded significant positive lieanr relationship with the ability to "concentrate well". The values of 'sig. (2-tailed)' for these correlations were less than the predetermined alpha value (0.01/2 = 0.025).

DISCUSSION

According to Malaysian Uniform Building by-law (UBBL), every room for residential purposes shall be provided with daylighting and natural ventilation by windows having a total area of not less than 10% of the clear floor area of such room and 5% of them shall be open able. Besides, every bathroom or toilet shall be provided with daylighting and ventilation by openings having a total area of not less than 0.2 m^2 and such openings shall be open able (Lembaga Penyelidikan Undang-undang, 2013). Although all the terraced houses complied with UBBL, the findings reflected that the current requirement of 5% WFR for natural ventilation is inadequate for comfortable and healthy living as many occupants felt that there was insufficient indoor air movement including in the toilets (refer to Figure 2).

The findings indicated that natural ventilation issues were more serious than daylighting issues in the terraced houses. One of the main reasons was the activities or tasks performed in terraced houses do not require high level of brightness, whereas most of the occupants in these houses relied on natural ventilation. Furthermore, the outdoor temperature is high and air velocity is low in Malaysia. Thus, more considerations shall be given to improve the indoor thermal comfort through proper passive ventilation strategies.

The mean scores for health problems were relatively high (above 3.00 – average) in spite of the low mean scores for natural ventilation and daylighting. The analysis of health issues demonstrated that indoor living environment in terraced houses affected both the physical and physiological health. Occupants may feel unhealthy due to dissatisfaction with the indoor environment. Psycho-social effects, which relate to emotional and behavioral responses, influence how occupants perceive and behave in certain environment (Loewenstein, 2001; Bluyssen, 2010). For example, discomfort indoor temperature and insufficient daylight brightness caused psychological health isssues (refer to Table 3 and 4).

The correlation tests evidenced significant linear relationship between indoor environment and health. The better the natural ventilation and daylighting performances in the terraced houses, the healthier the occupants perceived. On the contrary, the correlation tests proved that the relationships between behavior and natural ventilation as well as behavior and health were less significant. Only the relationship between behavior and daylighting was significant. For instance, the use of daylight for task performance gave significant effect on the occupants' behavior to control electric lighting.

The findings of this study suggest to review current terraced house design in relation to natural ventilation and daylighting. The existing intermediate terraced house unit with deep planning design is not effective for passive strategies. Lager openings (higher WFR) are needed to allow sufficient natural ventilation and air movement to avoid symptoms such as chest tightness and lethargy. However, proper shading of the openings is necessary to allow sufficient daylight while eliminating solar heat gain.

CONCLUSION

The study concludes that there is significant positive linear relationship between indoor environments and occupants' health. The current by-law requirement of 5% window-to-floor ratio for natural ventilation is inadequate for occupants' comfort and health, thus further review is needed. Proper consideration of natural ventilation and daylighting design strategies in terraced house is essential as it determines how the occupants can manage the indoor environment to achieve comfortable and healthy living environment.

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Thermal Comfort in Offices in India: Behavioral Adaptation and the Effect of Age and Gender

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ABSTR ACT

Reports on occupant's behavioral adaptation in India are limited in the literature. We analyzed the data from a recent thermal comfort field study of office buildings in two capital cities of Chennai and Hyderabad in India. Behavioral adaptation formed a key mechanism contributing to the subject's thermal comfort and user satisfaction in buildings. In mixed mode (MM) buildings, use of AC and/ or fan during temperature excursions proved to be an important and power saving adaptation. We present the logistic algorithms to predict the use of ACs and fans in MM buildings. Females, young subjects, and thin people had statistically significant and higher comfort temperature than males, older people, and obese occupants respectively. Females accepted the environments better. These findings might determine the design direction of future indoor environments. The occupants have undertaken several behavioral control actions throughout the year without many seasonal differences. Staying in airy place, drinking beverages, changing posture, and avoiding direct sunlight were the most prominent actions.

INTRODUCTION

Human existence hinges on thermal adaptation. In order to maintain the deep body temperature at 37 °C at all times, human beings adapt continuously. The adaptations are mainly physiological, psychological, environmental, and behavioral. Controlled by hypothalamus, physiological vasomotor regulation happens almost instantly. Human-envelop interaction greatly influences environmental and behavioral adaptation in buildings. This in turn also affects thermal satisfaction and energy consumption in them (Nicol & Humphreys, 2004; Brager, et al., 2004). Environmental adaptation by using various controls results in energy saving (Brager & Baker, 2009).

India's building energy consumption increased by about 3% per annum. It was 196.04 Million ton of oil equivalent in 2011, of which lighting, heating, ventilation, and air-conditioning constituted a major portion (IEA, 2011). India has an ever-widening energy supply-demand gap (Central Electricity Planning Authority, India, 2012). South India faces the maximum energy deficit of close to 30 %. Moreover, India is yet to have custom made adaptive thermal comfort standards. Recent research in Indian buildings proved that occupants in Indian buildings expressed comfort at much higher temperatures than expected (Indraganti, et al., 2014; Indraganti, 2010; Deb & Ramachadraiah, 2010; Dhaka, et al., 2013; Honnekiri, et al., 2014). Researchers attributed this to a wide range of adaptations in some of the studies. Understandably, mixed mode buildings with adaptive use of air-conditioners consume much lower energy than compared to the buildings air-conditioned throughout their active life.

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Indraganti (Indraganti, 2010a) reported the behavioral and occupant adaptation in apartments in India. Occupant adaptation with fans and windows and obstacles to adaptation in Indian offices were presented in Indraganti et al., (Indraganti, et al., 2014a). Others studied the mixed mode buildings for adaptation in summer (Honnekiri, et al., 2014). However, occupants undertake several behavioral control actions besides the operation of environmental controls in offices. They need investigation.

Sixty five percent of India's population is below 65 yrs. This gives it a rich demographic dividend (Basu, 2007). It particularly means that, India would have young population in the work environments and more women than is it now. Thermal necessities of this young group would be major drivers for design decisions in the future. Indian offices have about 25% female occupants now (Indraganti, et al., 2014). Researchers noted that occupant's age, body constitution, and gender influenced their comfort perceptions in both homes and offices (Indraganti & Rao, 2010; Karyono, 2000; Fanger, 1970). For improving thermal satisfaction in buildings, we need to understand them.

Therefore, this paper aims to explain the effect of age, body constitution, and gender on thermal comfort and highlights the user behavior in undertaking various adaptive control actions in offices in India. We also aim to develop algorithms to predict the use of air conditioners and fans in mixed mode offices. For this study, we use the long-term thermal comfort field study data obtained from offices in India (Indraganti, et al., 2014).

METHODS AND FIELD SURVEY

We conducted a thermal comfort field survey in 28 office buildings from 01-2012 to 02-2013. It was in two State Capitals: Chennai (N13°04' and E80° 17') and Hyderabad (N17°27' and E78° 28') with warm humid wet land coastal climate and composite climates respectively. These have four distinct seasons: summer, Southwest monsoon (SWM), Northeast monsoon (NEM) and winter. The surveys were paper based surveys. About 2787 occupants gave 6042 datasets. In all the offices close to the subjects at 1.1m level from the ground, we measured the indoor air temperature (T_a), globe temperature (T_g), air velocity (V_a), and relative humidity, while they filled in the questionnaires (Fig.1). High precision digital instruments and standard protocols were used with accuracies: thermometers: ±0.5 °C, hygrometer: ±5%, anemometer: ± 0.01 m/s. We spaced the surveys at four to six weeks.

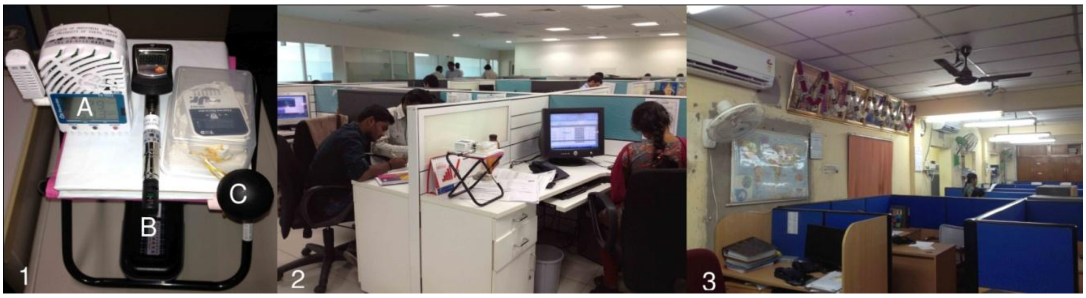

Figure 1 (1) The instrument setup, (A) Thermo-hygro meter (TR 76Ui), (B) Hot-wire anemometer (Testo 405) (C) Globe thermometer (TR 52i), (2, 3) Typical survey environments

The Survey Questionnaire

The questionnaire had three sections: (1) personal identifiers, (2) thermal responses and (3) Behavioral control actions undertaken (McCartney & Nicol, 2002). While the survey was going on, the interviewers noted down their clothing (I_{cl_tot}), activity (Met) and the personal environmental controls in use in that space. Thermal responses included standard questions on thermal sensation (TS); preference (TP); acceptability (TA); and sensation and preference for other environmental parameters. Indraganti et al. elaborated the methods and questionnaires (Indraganti, et al., 2014). We measured TS with ASHRAE's seven point scale having: cold (-3); cool (-2); slightly cool (-1); neutral (0); slightly warm (1); warm (2); and hot (3) and TA through a direct question with 0: acceptable; and 1: Unacceptable.

THE SUBJECT AND BUILDING SAMPLE

The occupants were in the age group of 18- 70 years and were associated with the environments for longer than three months. The age and gender profile of the subjects was similar in both the cities as shown in Fig. 2. Women constituted about 21 – 25 % of the sample. Majority of the subjects were in 25-35 years age group.

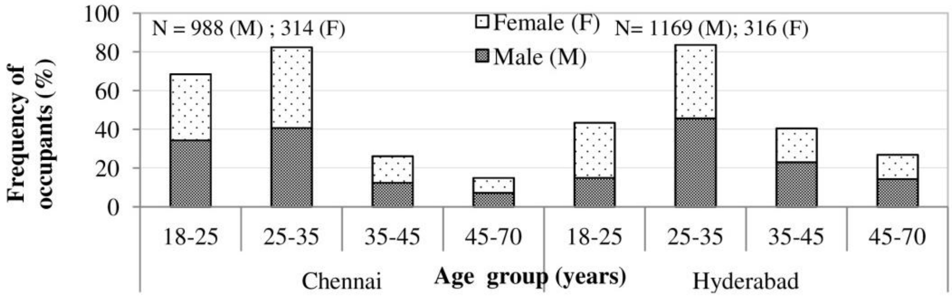

Figure 2 Age and gender profile of the subjects in the survey (M: Male; F: Female)

Building Types and Modes of Operation

We surveyed fourteen buildings in each city. These are of three types: (1) fully naturally ventilated, (2) mixed mode (MM) and (3) air-conditioned throughout (ACall). We had thirteen MM buildings, fourteen ACall buildings and one NV building. Of the total 6048 sets of data, 3804 came from the ACall and 2212 were from the MM buildings.

We collected thermal responses from the subjects when the buildings were operated in naturally ventilated (NV) mode and air-conditioned (AC) mode in all the buildings. However, due to frequent power outages, in some ACall buildings, AC was switched-off during an outage and the building was not run NV mode either. Data collected in ACall buildings with AC switched off is termed as ACoff. About 10 % of the data was collected in ACoff mode. We used the data collected in NV and AC modes here.

Table 1. Descriptive statistics of outdoor and indoor environmental variables

	NV						AC					
	C		H		All		C		H		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T_o (°C)	26.9	2.7	25.4	3.0	25.5	3.0	28.9	2.8	27.5	3.9	28.4	3.4
T_a (°C)	29.7	2.2	29.0	1.9	29.1	1.9	26.5	1.5	26.1	1.6	26.3	1.6
T_g (°C)	29.5	2.1	28.7	2.0	28.8	2.0	26.7	1.4	25.6	1.7	26.2	1.6
V_a (m/s)	0.46	0.33	0.13	0.21	0.17	0.25	0.15	0.20	0.05	0.08	0.11	0.17
RH (%)	59.7	5.5	43.1	11.1	44.7	11.7	50.1	7.5	45.6	10.8	48.2	9.3
I_{cl_tot} (clo)	0.69	0.08	0.71	0.08	0.70	0.08	0.71	0.09	0.69	0.06	0.70	0.08
Met (met)	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.0	1.0	0.1

C: Chennai; H: Hyderabad; SD: Standard deviation

RESULTS AND DISCUSSION

OUTDOOR AND INDOOR ENVIRONMENTS

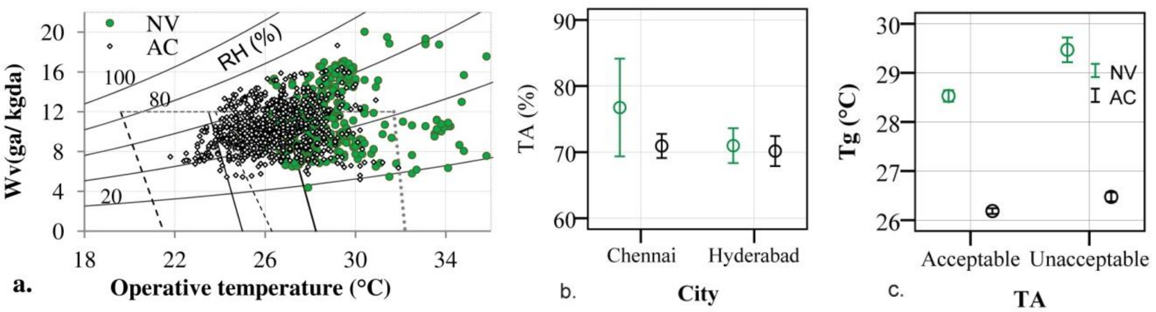

Figure 3 (a) Field survey data superimposed on the psychrometric chart; (b) Intercity variation in TA; (c) Modal variation in mean T_g when subjects voted on TA scale. Error bars indicate 95% CI.

Outdoors were hot in summer and warm through the rest of the survey. Being a coastal city

Chennai was more humid throughout, and Hyderabad was humid in monsoon seasons. We obtained outdoor daily mean temperature (T_o) data from meteorological records. Chennai indoors were significantly warmer and more humid than Hyderabad at 95% confidence interval (CI)(All declarations are at 95% CI unless and otherwise specified explicitly). Interestingly, we recorded 80% of the data in NV and AC modes when T_g was less than 29.8 and 27.5 °C and V_a was around 0.25 m/s and 0.15 m/s respectively. About 70% and 77% environments in NV and AC modes had humidity ratio (W_v) less than 12 g_a/kg_{da}, the upper limit suggested in ASHRAE Std-55 (Fig.3, Table 1) (ASHRAE, 2010; Indraganti, et al., 2014). Occupants achieved indoor air movement primarily by using the common fans and through the operation of openings in addition, in NV mode. A few ACall offices in Hyderabad did not have fans however. Women had slightly but significantly higher I_{ct_tot} than men did (N = 6048, $p < 0.001$).

SUBJECTIVE THERMAL RESPONSES

Fig.4 shows the probit lines of proportion voting on a given TS scale point (X) or lower against T_g. It also shows the probits for the proportion voting comfortable ($-1 \leq TS \leq 1$) and juxtaposed with the actual proportion comfortable. From these we can observe that in NV mode, 80% subjects voted in the central three categories on TS when $25.6 \leq T_g \leq 28.1$ °C.

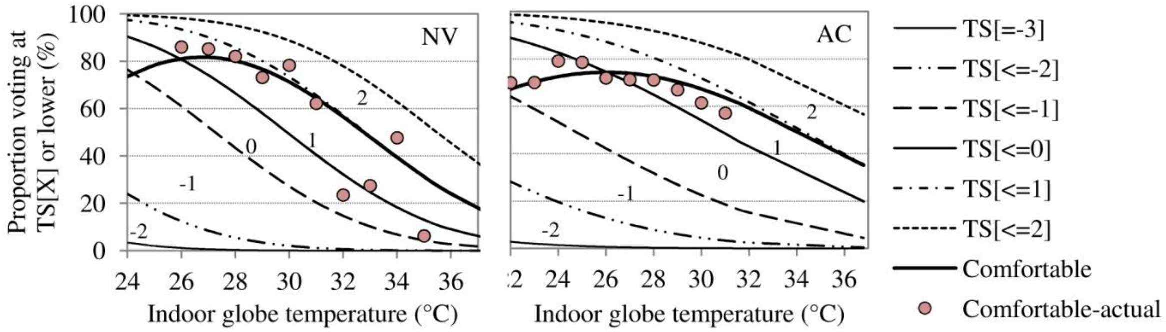

Figure 4 Probit lines indicating the percentage voting at a given TS scale point (X) and lower on T_g in NV and AC modes in India. Also shown are the probits for the proportion voting comfortable and the actual proportion voting comfortable ($-1 \leq TS \leq 1$) at each 1 K bin of T_g. X: Scale value of TS

Thermal acceptability remained the same at around 72 - 71% in both NV and AC modes. Interestingly occupants accepted the NV environments at 28.5 °C ($T_{g\text{-mean}}$) and in AC at 26.2 °C. (Fig. 3b,c) It may be possible that in AC environments, subjects' acclimatization to the narrower thermal regime perhaps had influenced the TA outcome. Brager and de Dear (Brager & de Dear, 2000) demonstrated that people who were exposed to a small range of temperatures (mostly through HVAC systems) developed high expectations for homogeneity and cool temperatures, and were soon critical of the subsequent thermal migrations indoors.

EFFECT OF GENDER, AGE, BODY FAT ON THERMAL ACCEPTABILITY AND COMFORT TEMPERATURE

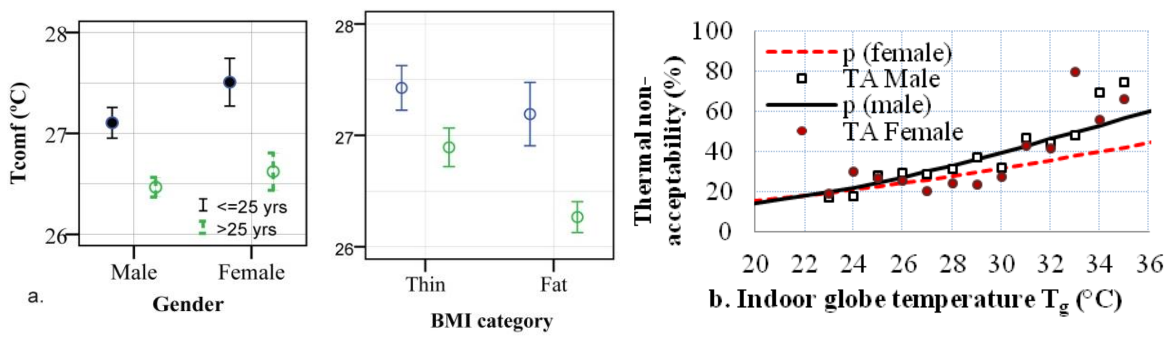

Figure 5 (a) Mean T_{comf} significantly varying with gender, body constitution, and age group; The

error bars indicate 95% CI. (b) Logistic regression T_g and TA for both the genders (p<0.001). Actual data are superimposed. More men were critical of an environment than women were.

We estimated the comfort temperature (T_{comf}) using the Griffith's method taking 0.5 as the coefficient, similar to others (Griffiths, 1990; Humphreys, et al., 2013). The comfort temperature varied with the outdoor temperature. Mean T_{comf} in NV mode was 28 °C and in AC was 26.4 °C. Notably, women had higher comfort temperature than men (Fig. 5). Similarly, subjects younger than 25 years old had higher T_{comf}, than the older group. At normal activity (1.0 met) and at common indoor clothing (Ict_tot ≤ 0.7 clo), we noted women having 0.6 K higher T_{comf} than men did. It equaled a sensation scale value of 0.22, (N = 3239, p<0.001).

Conversely, Parsons (Parsons, 2002) recorded no gender differences in thermal comfort for the same Met and Icl_tot. In this context, it is important to note that females in India are mostly (99%) dressed in loose fitting Indian attires, with much better scope for thermal adaptation (Indraganti, et al., 2014). This in part explains higher T_{comf} of women. A Finnish experiment, found TA in females significantly lesser than males. He attributed this in part to the unawareness about the thermostat and HVAC systems (Karjalainen, 2007).

The mean temperature where younger subjects accepted the environment was higher than that of their older counterparts. Women also accepted the environment better. For example, at 32 °C the acceptability among women was about 10.6 % higher as seen in Fig. 5b. We noted a similar trend between the two age groups. Researchers in Indonesia found men feeling warmer than women in offices (Karyono, 2000), unlike the Fanger's experiment on American and Danish subjects where there were no significant gender differences in comfort sensation (Fanger, 1970). This is despite the fact that women (mean 0.78 clo) had significantly higher clothing insulation than men (mean 0.68 clo) in India (N = 6048, p<0.001).

Thin subjects (body mass index (BMI) < 18.5 kg/m^2) (WHO, 2004) recorded comfort at 27.1°C while fat people (BMI > 25 kg/ m^2) expressed comfort at 0.7 K lesser (Fig 5a). Karyono also noted the same 0.7 K difference (N = 3865, p < 0.001), while Fanger recorded 0.26 K difference between thin and fat college age subjects (Karyono, 2000; Fanger, 1970). However, we found no statistically significant differences in acceptability among thin and fat people.

ALGORITHM TO PREDITCT THE USE OF CONTROLS IN MM BUILDINGS: AC AND FAN

In the era of power outages and expensive energy tariffs, mixed mode buildings with AC usage limited to the overheated periods come as a welcome respite. As the outdoor conditions became warmer, occupants adopted through ACs in mixed mode offices: for ex. during the mid-day and in summer and monsoon seasons. It formed an important adaptation strategy in addition to the use of fans. Use of AC in Chennai MM buildings was 82% (mean) while in Hyderabad MM, it was 20%. Chennai has very hot and humid climate, which could have triggered higher AC use. On the other hand, fan usage was much higher in Hyderabad MM. It was 78%, as against 43% in Chennai MM. Interestingly; in Chennai ACall buildings, we noted 20% fan usage, while ACall in Hyderabad had very few fans available.

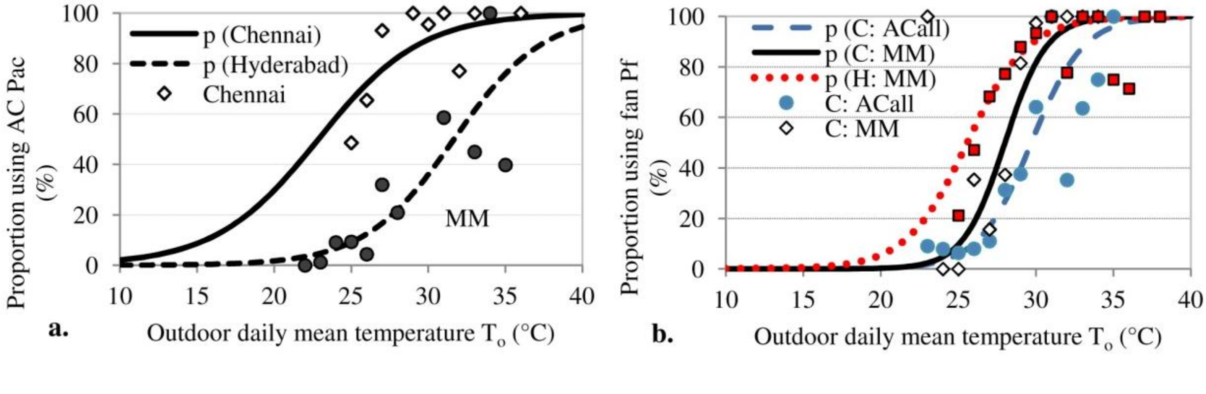

Figure 6 Logistic regression with outdoor daily mean temperature showing the proportion of (a) AC use in MM buildings in Chennai and Hyderabad; (b) fan use in ACall and MM buildings in Chennai

(C) and Hyderabad (H). Also shown juxtaposed are the actual proportions in 1K bins of T_o. For all the equations p<0.001, and slopes are significantly different at 95% CI.

The surveys provided binary data on the use of various environmental controls. We then applied the logistic regression on the 'control usage' against its stimulus (i.e. temperature) to develop the algorithm (Nicol, 2001; Rijal, et al., 2008). It yielded the following equations as shown in Table 2 and Fig. 6, where **p** is the probability of a control in use and $\mathbf{T_o}$ is the outdoor daily mean temperature.

Table 2. Logistic regression of AC and fan usage in Chennai (C) and Hyderabad (H)

Control	Case	Equation	Sample size	Negelekerke R^2	Standard Error
AC	C: MM	logit(p) = 0.30 T_o - 6.86	723	0.134	0.043
	H: MM	logit(p) = 0.35 T_o - 10.93	1489	0.394	0.02
Fan	C: ACall	logit(p) = 0.59 T_o - 17.62	1389	0.264	0.04
	C: MM	logit(p) = 0.75 T_o - 20.89	672	0.300	0.07
	H: MM	logit(p) = 0.51 T_o - 13.07	1356	0.143	0.05

Logit(p): Probability of a control being in use

From these equations, we can estimate that 89.4% and 28.5% ACs would be in operation when the T_o is at 29 °C for MM buildings of Chennai and Hyderabad respectively. Higher AC use in Chennai is perhaps due to its warmer thermo-hygro regime. Similarly, at T_o of 29 °C, nearly 40%, 68% and 85% fans would be on in Chennai-ACall, Chennai-MM, and Hyderabad MM buildings. Rijal et al. noted 81% fans on at 29 °C in Pakistan (Rijal, et al., 2008). It is important to note that in mixed mode buildings of Hyderabad, subjects have made use of the fans more than the ACs, making great energy dividends.

ADAPTATION THROUGH BEHAVIORUAL CONTROL ACTIONS

Occupants in real environments continuously adapt through various behavioral control actions. These vary with the thermal stimuli and happen in immediate response to the stimuli, throughout the day and year. These can vary with season. Therefore, we included a multitude of behavioral actions listed in Fig. 7 in the questionnaire. In all the surveys, the subjects chose from the fourteen possible behavioral control actions they must have undertaken during or fifteen minutes prior to the survey (Rijal, et al., 2010). These were noted down as binary data, an action in use: 1 and, not in use: 0. On analysis of the responses, we noted very few seasonal changes in the pattern of behavioral adaptation. Nevertheless, there were slight differences in NV and AC modes, overall.

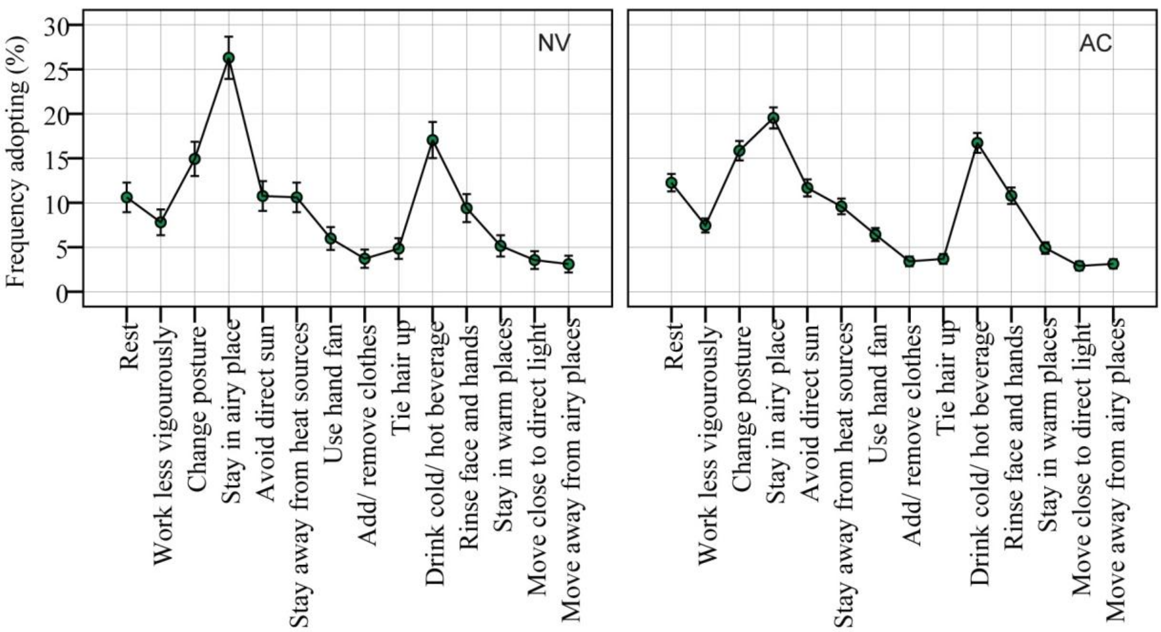

Figure 7 Proportion using various behavioral control actions round the year in both NV and AC modes. *Staying in airy place* is an important behavioral action. Error bars indicate 95% CI of mean.

Among all the adaptive actions, '*staying in airy place*, *drinking cold/ hot beverages, changing posture'* were most prominent in both NV and AC modes. In addition, in NV mode, occupants also '*avoided direct sun light, rested*, *rinsed face and hands* and *stayed away from heat sources.'* A higher percentage of subjects adapted through behavioral actions in NV mode than in AC mode, possibly due to the warmer conditions in NV. Similarly, subjects in Swiss offices consumed significantly more cool drinks as the temperature went up (Haldi & Robinson, 2008).

As the conditions in the offices continued to be slightly warm throughout the year, the adaptive actions generally used in winter conditions like, '*stay in a warmer place, move close to direct sunlight, move away from airy places,* were not used much. The seasonal differences were also not significant.

'Staying in airy place' was the most frequent behavioral action in summer (used by about 30 – 21 % in NV and AC modes). More importantly, subjects adopting this action encountered 0.9 K warmer indoor (T_a) environments and lower air speeds than otherwise ($N = 1487$, $p < 0.001$). Similarly, mean T_a in AC when people '*avoided direct sun*' was ⅓ K higher than otherwise, ($N = 4310$, $p = 0.001$). As we can see, subjects have adopted through these actions and responded to their immediate thermal environment.

Actions like *drinking cold and hot beverages* and *adding removing clothing /slippers* were some of the actions that subjects adopted in both summer and winter over a wide temperature regime. Female occupants predominantly preferred to use extra layers (sweaters or *Dupatta*/ shawls) adaptively when challenged by cold drafts. Indian ensembles like sari and *Salwar-Kamiz* were much more tenable for adaptation unlike the western outfits of men (Indraganti, et al., 2014). In addition, men had dress code while women had none. Liu et al. also observed season specific clothing adaptation in Chinese workplaces (Liu, et al., 2012). In addition to these, Rijal et al. found subjects taking extra showers and resting in summer in residential areas (Rijal, et al., 2010).

CONCLUSIONS

This paper discussed the behavioral adaptation and the effect of age, gender and body constitution on thermal comfort in Indian offices, relying on a recent field study data. The occupants undertook several behavioral control actions throughout the year. In mixed mode (MM) buildings, use of AC during temperature excursions proved to be an important and power saving adaptation. We presented algorithms to predict the AC and fan usage in always air-conditioned (ACall) and MM buildings in Chennai and Hyderabad. Females, thin people and the subjects under 25yrs age group had higher comfort temperature than males, 'over 25 yrs' age group and obese people. Women accepted the environments better. All these differences are statistically significant. The engineering significance of these differences may be limited, but these would determine the design direction of indoor environments of the future.

ACKNOWLEDGMENTS

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Factors Influencing Window Opening Behavior in Apartments of Indonesia

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ABSTRACT

This study aims to investigate the factors influencing occupants' window-opening behavior in apartments in the major cities of Indonesia. For this purpose, a field survey was carried out for 347 respondents in the city of Surabaya, covering detailed household and building profile, cooling energy consumption, thermal conditions, satisfactions and preferences, and duration and reasons for opening doors or windows. The results showed that the majority of respondents in the naturally-ventilated public apartments open at least one of the doors and windows during daytime (60-80%) and tend to close them during nighttime. In contrast, very few respondents in the air-conditioned private apartments utilize their openings. The respondents in public apartments tend to open either door or window on one side of living room, but not both. Privacy and security were found to be the main reasons affecting this behavior. The average duration of opening doors/ windows was 16-17 hours/day in the public apartments and less than 5 hours/day in the private apartments. Multiple regression analyses were carried out to further investigate the factors influencing the duration for opening doors/ windows. It was found that the opening behavior is highly influenced by not only thermal conditions, but also other factors such as size of balcony, size of corridor space, usage of cooling appliances, and background noise.

INTRODUCTION

Indonesia has been experiencing high economic growth and the middle class is now on the rise. The total population of Indonesia increased by more than double over the last four decades whereas the nationwide final energy demand rose by 14 times over the same period. The growing housing demand for the above emerging middle class is expected to require more apartments in the near future. In locations with high thermal stress such as Surabaya, the ownership of air conditioners is becoming less luxurious even in residential buildings (Ekasiwi, 2013). Therefore, it is important to determine energy-saving strategies for the future middle-class apartments.

Window-opening is considered to be one of the major adaptive behaviors of occupants to achieve their thermal comfort particularly in naturally ventilated houses in hot-humid climate. Studies by Rijal et al. in UK and Japan (2007, 2013) showed that the highest usage of window-opening was found in summer and the lowest was in winter. Since the number and size of openings in apartments are limited,

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window-opening/closing behavior may affect their thermal comfort more significantly compared to that in landed houses.

The behavior of opening windows may also have direct effects on energy consumption for cooling by changing air-flow rate inside the buildings (Fabi et al., 2012). Therefore, the factors affecting people's behavior of opening or closing their windows are continuously studied. Finding these factors may help architects to create designs which can encourage people to actively open their windows.

To date, most of the relevant studies tried to examine the relation between window-opening behavior and thermal conditions. This is because the action of opening windows are assumed to be stimulated by people's reactions to thermal discomfort. The frequency and length of opening windows were found to be much less in air-conditioned buildings rather than those in naturally ventilated buildings (Rijal et al., 2007, and Rijal et al., 2013). Nevertheless, there are various other factors that may affect the behavior of opening windows, including physical environmental, contextual, psychological, physiological, and social factors (Fabi et al., 2012). Nonetheless, studies involving social and psychological factors are mostly conducted not in the field of building science, but in psychology. This paper aims to investigate various factors influencing window-opening behavior in apartments in hot-humid climate of Indonesia.

METHODS

Surabaya is located on 7°9'21" South Latitude and 112°36'-57" East Longitude. It is the capital city of East Java Province and the second biggest city in Indonesia. The city has a hot-humid climate, with monthly average temperature ranging from 27.2-29.0°C, monthly average relative humidity of 65.9-80.9%, and monthly average wind speeds of 2.12-3.10m/s (NCDC, 2014).

Both private and public apartments in Surabaya were addressed in this study (Fig. 1a). Private apartments are normally high-rise buildings and contain 14-33 floor heights. Most of the houses in private apartments are equipped with air-conditioners. On the other hand, public apartments contain 3-5 floor heights and almost all the houses are naturally ventilated. Public apartments were initially built to resettle slum squatters for providing better living environments (hereafter, 'old public apartment'). However, since 2008, the target was extended into low to middle income classes in response to housing demand (hereafter, 'new public apartment'). In this study, 8 public and 8 private estates from a total of 48 housing estates were selected through proportional stratified samplings (Table 1).

The field survey was conducted from September to October 2013, consisting of face-to-face interviews and one-week thermal measurements. The interviews covered 347 respondents, comprising the following detailed information: (1) household and building profile, (2) energy consumption and usage of cooling appliances, (3) thermal satisfactions and preferences, and (4) duration and reasons for

Figure 1 (a) Views of apartments from each category and (b) one week thermal measurements

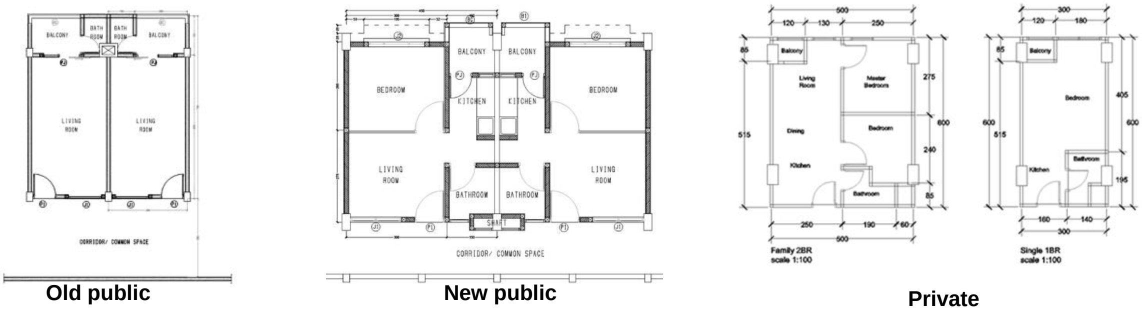


Figure 2 Typical room arrangement in apartments

opening doors or windows. One-week thermal measurements were conducted in 30 apartment houses to measure globe temperature, indoor and outdoor air temperature, and indoor and outdoor relative humidity. Globe temperature was measured using TR-52i (T&D Corporation) by inserting the sensor into a black-painted-Ping-Pong ball. The Ping-Pong ball was then positioned at 110 cm height above floor. Indoor air temperature and relative humidity were measured using TR-72ui (T&D Corporation) which was placed slightly below the Ping-Pong ball. The equipment was installed in the living room and set to avoid direct sunlight. Outdoor measurement instruments (TR-73ui; T&D Corporation) were placed in open spaces at a certain height under the shade to prevent the effect of solar radiation (Fig. 1b).

RESULTS AND DISCUSSION

Profile of Respondents

As shown in the Table 1, the average household sizes are 3.5 to 3.6 for the public apartments and 1.9 for the private apartments. Age of respondents ranges from 20 to more than 60. The monthly average household income is the highest in the private apartments. More respondents in the new public apartments have a higher income than those in the old public apartments. Typical unit in public apartments (both old and new) consist of a room, a balcony, and a bathroom; with floor areas of 18-21m² (Fig. 2). However, the newest type in the new public apartments has slightly larger floor areas (24-32m²) and consists a bedroom, a living room, a kitchen, a bathroom, and a balcony. On the other hand, private apartments have two types of room arrangements. The first is single room which contains only one room (for bedroom and kitchen) and a bathroom. The second is family room which has two bedrooms, one living room (also functioning as kitchen and dining room), and a bathroom.

Daily Usage Pattern of Window Opening Behavior

The following four typical openings in apartments are considered in this paper: front door, front window, back door, and back window. In most of the apartments, the front door (facing corridor space) is directly placed on one side of the living room, whereas the back door is normally placed on the rear side of the living room adjacent to the balcony. The size of the doors per floor area ranges from 6% to 10%, whereas the size of windows per floor area ranges from 2% - 8%. The size of balcony per floor area ranges from 9% - 22% and the size of corridor space per floor area ranges from 15% - 28%.

As shown in Table 2, the respondents use their openings for 14.8 hours on average. The average opening duration during daytime (6:00-18:00) (9.7 hours) is almost two times longer than that of nighttime (5.1 hours). This tendency is seen similarly for all the categories. In the private apartments, the average duration of opening doors or windows is very short, even in daytime (less than 5 hours). The respondents in public apartments tend to open their doors (12.8 hours) for a longer period than to open

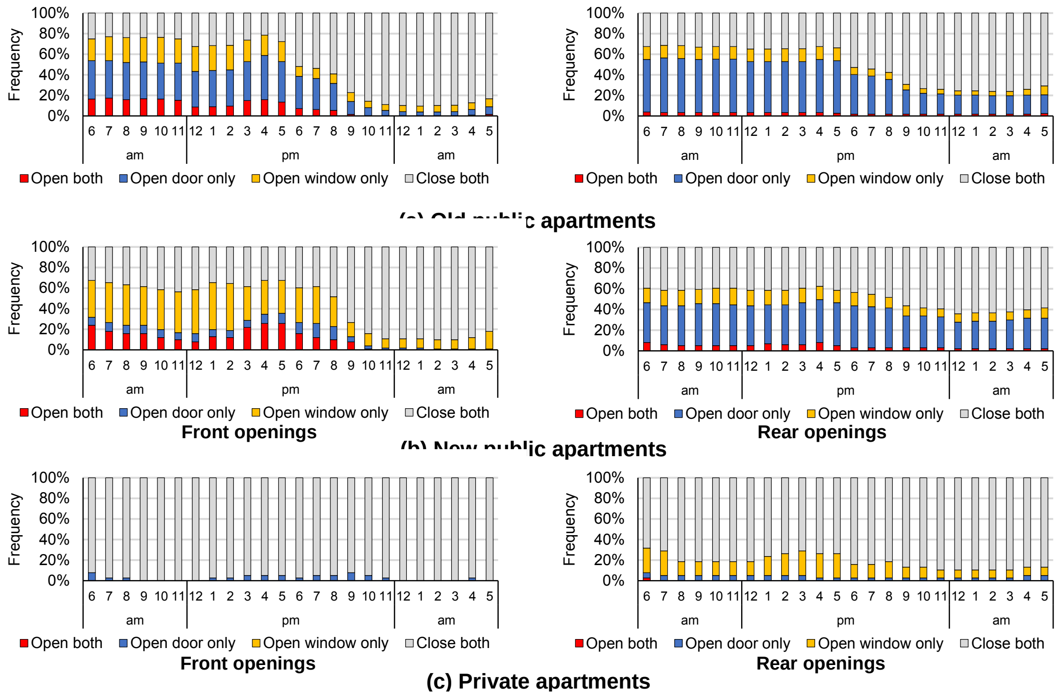
Table 1 Profile of respondents

	Whole sample	Old public	New public	Private
Sample size	347	208	101	38
Household size (persons)	3.5	3.6	3.5	1.9
Age (%)				
20-30 (years old)	22.0	13.8	25.3	70.4
31-40	34.6	38.3	32.6	14.8
41-50	25.2	30.0	22.1	3.7
51-60	11.3	11.7	12.6	3.7
>60	7.0	6.6	7.4	7.4
Monthly income (%)				
<100 (US$)*	7.5	8.7	7.9	-
100-200	36.9	49.0	23.8	5.3
200-300	21.0	21.6	26.7	2.6
300-400	12.4	11.5	15.8	7.9
>400	10.4	6.3	18.8	10.5
No. of apartments				
Built before 2008	7	5	-	2
Built after 2008	9	-	3	6
Floor area (m²)	18-38	18-21	24-32	18-38

*exchange rate: 1 IDR=9,387 USD (Average per 2012, The World Bank)

Table 2. Average hours for opening doors or windows

	Whole sample	Old Public	New Public	Private
All openings	14.8	15.5	17.0	4.8
Day	9.7	10.5	10.4	3.1
Night	5.1	4.9	6.6	1.7
Doors	11.5	12.8	12.8	1.4
Windows	8.1	7.6	10.6	3.4
Front door	5.8	7.5	4.6	0.7
Front window	6.2	5.6	8.6	-
Back door	8.5	9.1	10.2	1.0
Back window	2.9	2.8	3.5	3.4



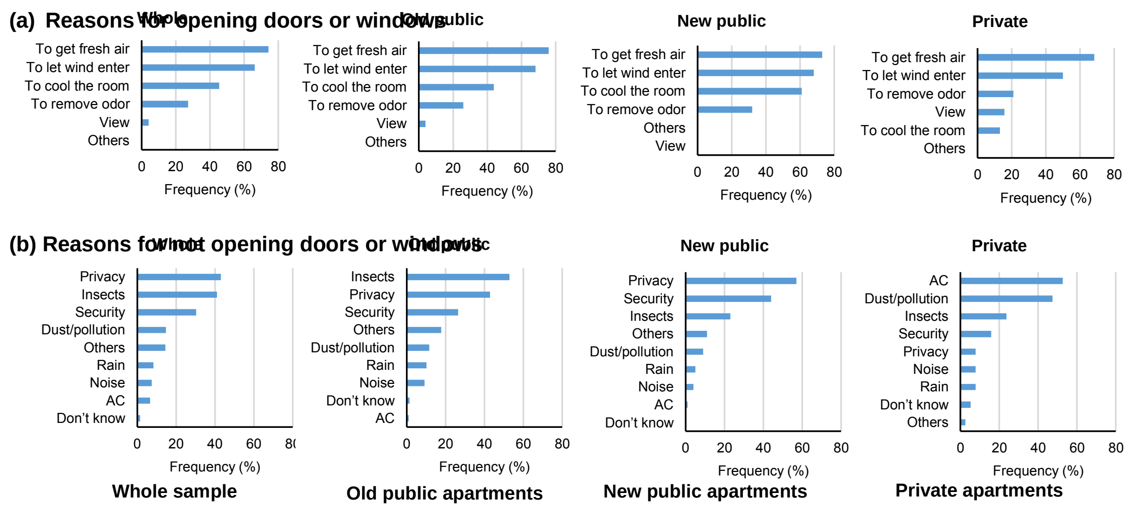


Figure 4 Reasons for: (a) opening doors/windows; and (b) closing doors/windows

windows (7.6 and 10.6 hours for old and new public apartments respectively). In contrast, the respondents in private apartments tend to open their windows (3.4 hours) longer than doors (1.4 hours). The back door is used the longest (8.5 hours), whereas the back window is least used (2.9 hours). This tendency is found similarly among the respondents in public apartments. In contrast, the respondents in private apartments tend to open their back window longer than other openings (3.4 hours). The respondents in the old public apartments tend to open their front door longer by 1.9 hours than the front window, while those in new public apartments tend to open the front window longer by 4.0 hours than the front door.

The daily usage patterns of doors and windows in each category are showed in Fig. 3. The figure clearly shows that the occupants in the public apartments (both old and new) open at least one door or window in both front and rear side of living room particularly during daytime (60-80%), while those in the private apartments rarely open doors or windows (0-30%). In general, most of the respondents in public apartments tend to open only one opening for one side of unit at one time. Less than 20% of the respondents open both windows and doors even during daytime. In the case of old public apartments, the usage of front door (40-60%) was higher compared to the front window (30-40%). In contrast, the respondents in the new public apartments tend to open the front window (50-60%) more than the front door (20-40%). About 40-50% of the respondents of both public apartments open only the back door and tend to close the back window. In the nighttime, the respondents in both apartments tend to close their front window and door, while 20-40% of them still open the back door.

Reasons for Opening and Closing Windows

Fig. 4 illustrates major reasons for respondents to open or close their doors or windows. The highest reasons were found to be: ‘obtaining fresh air’ (74.3%), ‘letting wind to enter’ (66.2%), and ‘to provide cooling’ (45.4%) for all the categories. On the other hand, the top reasons for not opening doors or windows were different for each category: ‘AC usage’ (52.6%) for the private apartments, ‘insects’ for the old public apartments (52.9%), and ‘privacy’ (57.0%) for the new public apartments. ‘Security’ reason may especially affect the closing behavior during nighttime, while ‘privacy’ may be the main reason for closing behavior during daytime. As previously discussed, the pattern and average duration of opening front door and window were different between old and new public apartments, unlike the back door and window (see Fig. 3). Furthermore, the respondents were found to open either door or window on one side of living room, but not both. Fig. 4 implies that the occupants in new public apartments are more concerned about privacy and security than those in old public apartments. In the old public apartments, these concerns should be less because most of the residents were relocated from the same areas. This may be one of the reasons for opening front door more in the old public apartments than those in the new public apartments.

Thermal Conditions

Fig. 5 shows the results of one-week thermal measurements. As indicated, the outdoor air temperature ranges from 25.6-36.7°C whereas the relative humidity ranges from 27-77% during the measurement periods. The indoor air temperature ranges from 29.1-33.0°C for naturally ventilated apartments (i.e. public apartments) and 25.8-31.6°C for air-conditioned apartments (i.e. private apartments). Even in the naturally ventilated apartments, the diurnal air temperature ranges are smaller than that of the outdoor temperature, though the mean indoor air temperatures in both old and new public apartments are slightly higher than the mean outdoor air temperature (30.3°C). The previous results showed that most of the occupants open doors or windows particularly during daytime (see Fig. 3). This implies that the ventilation rates in these public apartments were not necessarily sufficient to change the indoor air even when the doors or windows were opened during daytime.

Thermal Sensations and Preferences

Fig. 6 shows the sensation and preference of respondents for thermal condition, air flow, and humidity in the living room during the day. The sensations were measured in a 7-point scale while preferences were measured in a 5-point scale. More than 57% of the respondents regard the thermal condition in their living room as ‘warm’ to ‘hot’ even for those in the private apartments. Accordingly, the preferences for cooler environments are evident (more than 68%). Despite the use of air-conditioners, more than 97% of respondents in the private apartments prefer cooler indoor conditions. Meanwhile, more than 40% of the respondents found humidity in the living room to be ‘slightly humid’ to ‘very humid’, thus they prefer ‘less humid’ conditions (38.5%). As for the indoor air flow, more than 70% of respondents consider it to be ‘slightly high’ to ‘very high’. However, more than half of the

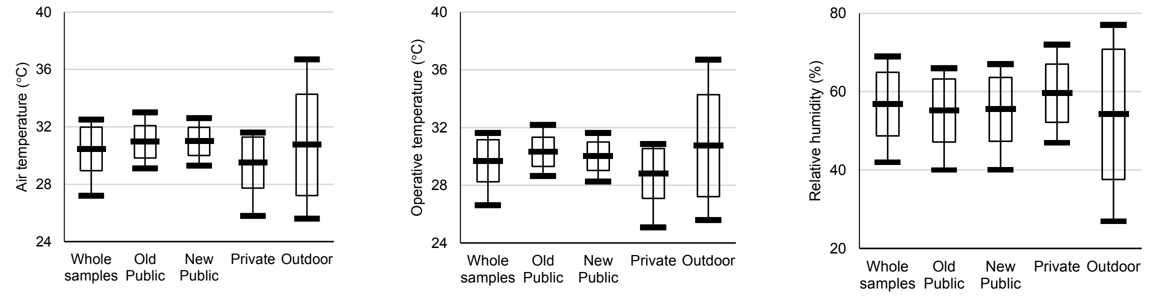
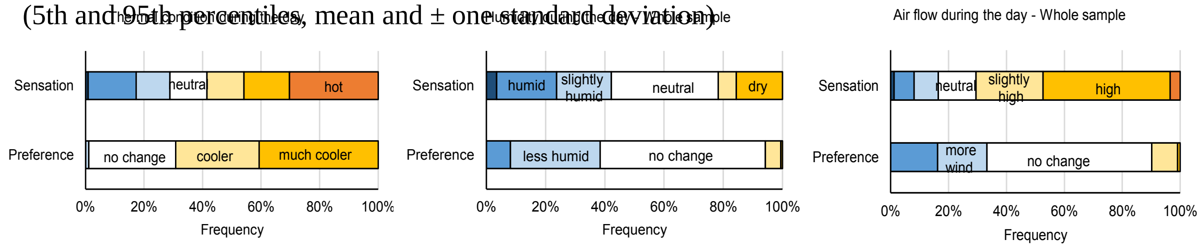


Figure 5 Statistical summary of air temperature, operative temperature, and relative humidity (5th and 95th percentiles, mean and ± one standard deviation)



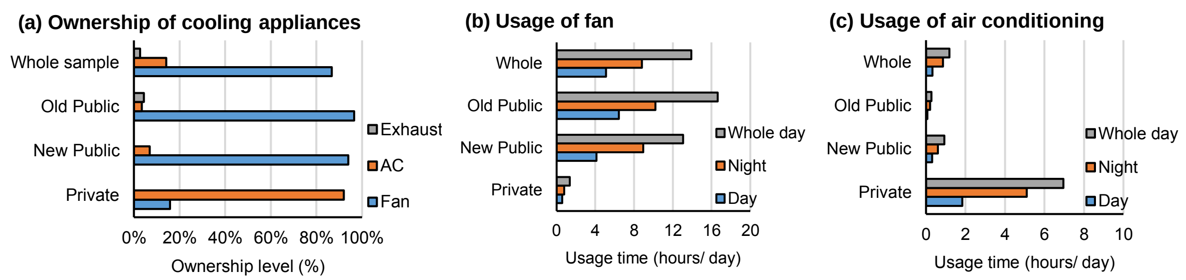


Figure 7 Ownership and usage of cooling appliances

respondents do not prefer to change the current air flow conditions, while about 30% prefer even higher air flow. This result clearly indicates their high preference for a better air flow condition in their apartments.

Usage of Fan and Air Conditioner

Fig. 7 shows the ownership and usage of cooling appliances in respective apartments. More than 90% of houses in public apartments (both old and new) owned one or more fans, whereas more than 90% of houses in private apartments were equipped with air conditioner. The average daily usage time of fan is 16.7 hours for old public apartments, 13.1 hours for new public apartments, and 1.4 hours for private apartments. The occupants in public apartments use fan longer during nighttime (10.2 hours and 8.8 hours) than daytime (6.4 and 4.1 hours), in contrast with the usage of doors/windows (see Table. 2). On the other hand, the usage of air conditioner was the highest in private apartments (5.1 hours during nighttime and 1.9 hours during daytime).

Factors Influencing Window Opening Behavior: Multiple Regression Analyses

Multiple regression analyses were carried out for five target variables: (a) daily usage of doors/windows, (b) daytime usage of doors/windows, (c) nighttime usage of doors/windows, (d) daily usage of doors, and (e) daily usage of windows. In this analysis, thermal conditions are represented by thermal sensations and preferences. A total of 44 variables were considered. Step-wise method with pairwise deletion was utilized to determine the factors which best explain the window opening behavior of apartments' users in Surabaya.

The result for daily usage of doors/windows (Table 3a) shows that high correlations are presented by 'size of balcony' (0.24***) and 'size of corridor space' (0.22***). As the size of these two transition space larger, the duration of opening doors/windows tend to be longer. 'Energy for cooling' decrease when the duration of opening doors/windows increase (-0.18**), in contrast with 'usage of fan' during daytime (0.18**). On the other hand, the daily usage of doors/windows tend to be longer when the respondents prefer noisier condition (0.12*). During daytime (Table 3b), 'size of balcony' and 'usage of fan' remain to have high influences (0.19***), followed by 'monthly income' (-0.18***) and 'size of household' (0.16**). This means that respondents with higher income tend to open their door/windows shorter during daytime. Further, space limitation can be one of the reasons for the respondents with higher household size to open their doors/windows longer during daytime. 'Preferences for thermal condition' shows relation of 0.12* which implies that daytime usage of doors/windows is longer when the respondents has adjusted with hotter thermal condition. During nighttime (Table 3c), influences are showed by 'preferences for background noise' (0.14*) and 'energy for cooling' (-0.13*).

Table 3d shows that the duration of opening doors tend to be longer when the 'size of balcony' and 'size of front openings' increase. 'Preferences for background noise' also give influence of 0.19***, followed by 'sensation for air quality' (0.15**), 'floor level' (-0.13*), and 'quality of life' (-0.12*). In most of apartments in Indonesia, first floor is used for public spaces instead of living spaces. Thus, the negative correlation from 'floor level' might be caused by other reason such as 'age of respondents'. In fact, the relation of 'age' and floor level is -0.29***, which indicates that older people tend to live in the lower floor. It is predicted that people in older age who mostly live in those apartments longer tend to open their door longer than younger respondents. On the other hand, 'size of corridor space' has positive correlation with duration of opening windows (0.48***, Table 3e), in contrast with 'size of front openings' (-0.15**). This perhaps indicates that rather than the 'size of front openings', size of corridor space play more important role in encouraging the respondents to open their windows longer. 'Preferences for natural lighting during the day' and 'satisfaction for life' also show influences to the daily usage of windows with correlation of 0.13* and 0.11*, respectively.

Table 3 Results of multiple regression analysis, explaining window opening behavior in apartments of Surabaya

(a) Daily usage of doors/windows

Independent variable	β		r	
Size of balcony per floor area	0.24	***	0.24	***
Size of corridor space per floor area	0.22	***	0.15	**
Energy for cooling	-0.18	**	-0.16	**
Usage of fan during daytime	0.18	**	0.16	**
Preferences for background noise	0.12	*	0.19	***
R^2	0.19	*		
Adj. R^2	0.17	*		
n	331			

(b) Daytime usage of doors/windows

Independent variable	β		r	
Size of balcony per floor area	0.19	***	0.29	***
Usage of fan during daytime	0.19	***	0.26	***
Monthly income	-0.18	***	-0.25	***
Size of household	0.16	**	0.25	***
Energy for cooling	-0.13	*	-0.11	*
Preferences for thermal condition during the day	0.12	*	0.11	*
R^2	0.23	*		
Adj. R^2	0.21	*		
n	331			

(c) Nighttime usage of doors/windows

Independent variable	β		r	
Preferences for background noise	0.14	*	0.15	**
Energy for cooling	-0.13	*	-0.15	**
R^2	0.04	*		
Adj. R^2	0.03	*		
n	331			

(d) Daily usage of doors

Independent variable	β		r	
Size of balcony per floor area	0.37	***	0.39	***
Size of front openings per floor area	0.20	***	0.12	*
Preferences for background noise	0.19	***	0.19	***
Sensation for air quality	0.15	**	0.14	**
Floor level	-0.13	*	-0.24	***
Quality of life	-0.12	*	-0.17	***
R^2	0.29	*		
Adj. R^2	0.26	*		
n	331			

(e) Daily usage of windows

Independent variable	β		r	
Size of corridor space per floor area	0.48	***	0.31	***
Size of front openings per floor area	-0.15	**	-0.15	**
Preferences for natural lighting during the day	0.13	*	0.20	***
Satisfaction for life	0.11	*	0.12	*
R^2	0.27	*		
Adj. R^2	0.25	*		
n	331			

CONCLUSIONS

(1) The respondents in the naturally ventilated public apartments showed relatively high utilization of openings on both front and rear side of unit during the daytime (60-80%), whereas very few respondents in the air-conditioned private apartments open their doors/ windows (0-30%). In the public apartments, the occupants tend to open either window or door on each side of unit, but not both. The respondents in the old public apartments open their front door more than the front window during daytime, in contrast with the respondents in the new public apartments. In the case of rear opening, the respondents in both old and new public apartments tend to open the back door rather than back window. The average duration of opening doors/windows was 16-17 hours/day in the public apartments and less than 5 hours/day in the private apartments. Obtaining fresh air, letting wind enter, and obtaining cooling were the main reasons for respondents to open doors/windows, whereas concerns of privacy and security may be the reasons for them to close their doors/windows.

(2) The diurnal indoor air temperature ranges in the selected apartments were smaller than that of the outdoor temperature, even for naturally ventilated apartments. It indicates that the ventilation rates in these apartments were not necessarily sufficient to change the indoor air even when the openings were utilized.

(3) The occupants tend to perceive their thermal condition as ‘hot’, thus the preference for cooler indoor condition was evident. To improve their thermal comfort, the occupants in naturally ventilated apartments tend to increase indoor air speed to enhance skin evaporation by opening doors/windows. Fans were also utilized to further increase the air speed, especially during the nighttime. Correspondingly, most of the respondents regarded their sensation for air flow as ‘high’ and prefered ‘no change’ or ‘more air flow’ for the current air flow condition.

(4) The results of multiple regression analyses implied that among the selected factors, the behavior of opening and closing doors/windows is affected not only by thermal sensations and preferences, but also building profiles and usage of cooling appliances. Major factors included ‘size of balcony’, ‘size of corridor space’, ‘usage of fan’, ‘energy for cooling’ and ‘preferences for background noise’. In designing apartments, more attention should be drawn to the size of balcony and corridor space to encourage the occupants to more actively open their doors/windows.

(5) In this study, air temperature, relative humidity, and globe temperature were measured during one week period. In the future study, the resulting indoor air flow and air change rates under the open/closed window conditions should be analyzed to further understand the occupants’ adaptive behavior by opening windows.

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Session 2D : Tools and methods/ framework

PLEA2014: Day 1, Tuesday, December 16
14:10 - 15:50, Trust - Knowledge Consortium of Gujarat

PLEA 2014 Ahmedabad

An Operational Indicator System for the Integration of Sustainability into the Design Process of Urban Wasteland Regeneration Projects

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ABSTRACT

In the context of sustainable development of European post-industrial cities, urban wastelands offer an important potential of surfaces to recapture. The regeneration of these sites is indeed an opportunity to simultaneously create density within the existing built fabric and revitalize some portions of cities and metropolitan areas. Although the launching of several initiatives of this type can be observed, their implication toward sustainable development is in most cases implicit and superficial. In point of fact, integration of sustainability into urban wasteland regeneration projects cannot be summarized by a mere density issue. It requires a proactive search for global quality, implemented in a participative way into the project dynamics, and a continuous monitoring of environmental, social and economic dimensions adapted to such projects. Specifically addressing these considerations, this paper introduces the development of an operational indicator system for the integration of sustainability into the design process of urban wasteland regeneration projects. It aims to provide a tool for structured and continuous evaluation, hinged on their specific characteristics, and to give useful basis to stakeholders involved in their management. Subsequently, the paper presents a first test application performed on a project underway in Switzerland, which validates its usability. Further work suggests the integration of the system into a digital monitoring tool in order to make it applicable to a variety of projects of this type.

INTRODUCTION

Although Urban Wasteland Regeneration Projects (UWRP) embody a strategic potential to revitalize and densify existing urban fabrics, they are often not as sustainable as they may seem (Rey, 2007). Indeed, this strategy - as part of the compact and polycentric city model (Jenks, 1998; Rogers & Gumuchdjian, 1998) - is no guaranty of inclusion of the three pillars of sustainability: the economic, the ecological and the sociocultural (Andres & Bochet, 2010). Integration of sustainability into UWRP goes through the pursuit of a global quality and a constant follow-up of environmental, sociocultural and economic dimensions adapted to projects on those sites (Rey, 2012). In this sense, existing evaluation

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systems for large scale developments (LEED ND, BREEAM communities, HQE aménagement, DGNB New urban districts, etc.) do not address the specificities of UWRP. Therefore, few studies have developed methodologies for sustainability assessment adapted to the characteristics of the projects located on these sites. However, our analysis reveals that they are dissociated from the design process and do not totally address the specificities of UWRP. As a result, none of them are currently operational. Hence, the purpose of this paper is to introduce SIPRIUS (Rey, 2012), an operational indicator system for the integration of specific sustainability issues into the design process of such projects, as well as the methodology that precedes its development. Afterwards, a test application on a case study in Neuchâtel (Switzerland) demonstrates the relevance and applicability of the indicator system to UWRP.

SPECIFICITIES OF UWRP

Wastelands have a unique identity, whether positive or negative (cultural symbol, economic and social stigma, sense of insecurity, risk of contamination, etc.). Projects on these sites are not limited to a single building. Quite the contrary, their scale ranges from urban planning to architectural design. Hence, neighborhood scale seems the most appropriate to encompass the full implications of these projects (CABERNET, 2006). But unlike new neighborhood developments, urban wastelands are already transformed and yet abandoned. Economic and ecological potential of existing buildings – and consequently architectural heritage – implies making decisions on the level of conservation (OFEN, 2013). Moreover, because they are disconnected from their urban context and emptied from permanent population, projects on wastelands neither can be considered as neighborhood renewals.

Urban wastelands are not irreversible but their regeneration is highly complex. This is due in part to the long duration of the regeneration process, which involves a variation of several elements (conditions, needs, modification of general terms, changes in project leaders and actors, etc.). Moreover, the implication of a multitude of stakeholders with varying degrees of influence and interest tends to complicate the process (Doak & Karadimitriou, 2007).

REQUIREMENTS FOR THE OPERATIONAL INDICATOR SYSTEM

Given their specificities, having a clear idea of where UWRP are heading in terms of sustainability is crucial to build a solid foundation for their future (Hollander, Kirkwood, & Gold, 2010); particularly since most UWRP refer partially to sustainable development, generally in favor of environmental aspects (Franz, Pahlen, Nathanail, Okuniek, & Koj, 2006). These considerations call for the development of an operational indicator system tailored to the needs of UWRP in order to integrate sustainability into their design process. This objective is reflected in the following specifications:

1. Search for a global quality: The indicator system covers a relatively wide range of parameters to address the environmental, social and economic sustainability, equally and concurrently;
2. Appropriateness to UWRP: The indicator system meets the specificity inherent to UWRP. In particular, adaptation to the scale and complexity of the project and consideration of an already built-up site;
3. Inclusion of the principles of monitoring: The indicator system ensures an operational assessment, i.e. visualization of the various phases of the project and establishment of reference values in order to follow and act on performance trends.

METHODOLOGY

The methodology used to establish the indicator system is based on three main steps, namely the determination of criteria, indicators and then reference values for each indicator. It is worth nothing that a test application was done in parallel with the construction of the indicator system, which helped to perform various practical settings and iterative improvements.

Identification of criteria

The first step is to determine a list of criteria that portrays the multidimensional aspects of UWRP in the context of sustainable development. In this sense, the list of criteria endeavors to give an equivalent importance to the three pillars of sustainability. It is based on the definition of fundamental objectives of sustainability and on operational considerations coming from practical experience of the test application. Given the requirements related to the project's scale, the identification of criteria seeks to distinguish those that refer to the context of those that refer to the project.

1. Context criteria: concern aspects which are clearly beyond the physical boundaries of the site. Either the project has an impact in a wider sphere than that defined by the wasteland or external factors interact with the project;
2. Project criteria: involve aspects whose issues are within the boundaries of the site. These criteria relate to built-up and unbuilt areas.

Identification of indicators

To assess the selected criteria, it is necessary to determine one (or more) indicator(s) that is a "value" that can be "measured" to indicate the degree of satisfaction with each criterion. It is essential to note that the notion of value is to be understood in its broadest sense: it can be both qualitative and quantitative, provided that it gives an explicit indication on the project. To ensure the legitimacy of the system, the selection of indicators is subject to a number of methodological rules and fundamental principles (Bossel, 1999). They stress that the indicator should be:

1. Exhaustive: together, represent proportionally and holistically the three dimensions inherent to the concept of sustainable development;
2. Relevant: synthetically reflect the performance of the project in relation to a given criterion;
3. Sensitive: respond significantly to variations of the parameter that is evaluated for both quantitative and qualitative indicators;
4. Objective: eliminate ambiguity. Requires a precise definition of the indicator and its evaluation method;
5. Accessible: depend on known values or known quantities and reflects the reality of the usual practice. Quantitative indicators must be easily calculated, qualitative indicators depend on a clear description;
6. Readable: ensure simplicity of interpretation, as it is intended to contribute to decision-making and to communication of the results to multidisciplinary stakeholders.

Identification of reference values

Finally, reference values are defined for each indicator. These values may correspond to quantitative data, from overall performance encountered in professional practice, or qualitative characteristics, defined by a description of specific issues or concrete elements that are related. Aiming to include monitoring principles, a set of determined values is used for the measurement and follow-up on project performance.

1. Limit Value (V_L): Minimum value required for any project (or veto value);
2. Average Value (V_A): Value corresponding to the usual practice, no particular performance;
3. Target Value (V_T): Value to target in order to achieve a greater performance;
4. Best Practice Value (V_B): Value corresponding to a particularly high performance.

RESULTS

Operational indicator system - SIPRIUS

The selection and identification of criteria and indicators, followed by the definition of reference values, led to the creation of an operational indicator system. Entitled SIPRIUS, it is a catalog from which planners can choose indicators considered as significant for the monitoring of their UWRP. Depending on the specific characteristics of some projects, it is possible to add indicators to those already provided. SIPRIUS is composed of 9 criteria and 21 indicators relating to the context **presented in Table 1** as well as 12 criteria and 21 indicators relating to the project **presented in Table 2**.

Table 1. Summary List of Criteria and Indicators Related to Context

Sustainability Pillar	Criterion Code	Criterion Title	Indicator Code	Indicator Title
Environment	C1	Mobility	C1a	Quality of service in public transport
			C1b	Number of parking spaces
			C1c	Tying status with soft mobility networks
	C2	Pollution	C2a	Average annual emission of NO_2
			C2b	Acidification Potential (AP)
			C2c	Global Warming Potential (GWP)
	C3	Noise	C3a	Average emission of noise - day
			C3b	Average emission of noise - night
Sociocultural	C4	Proximity of school facilities	C4a	Average distance to a nursery
			C4b	Average distance to kindergarten
			C4c	Average distance to an elementary school
			C4d	Average distance to a junior school
			C4e	Average distance to a high school
	C5	Proximity of commercial facilities	C5a	Average distance to a commercial zone
	C6	Proximity of recreational facilities	C6a	Average distance to a public park
			C6b	Average distance to a recreational greenspace/natural area
			C6c	Average distance to a cultural center
			C6d	Average distance to a sport center
Economy	C7	Population	C7a	Net population density
	C8	Job	C8a	Net employment density
	C9	Local Economy	C9a	Proportion of work by local companies

Table 2. Summary List of Criteria and Indicators Related to Project

Sustainability Pillar	Criterion Code	Criterion Title	Indicator Code	Indicator Title
Environment	P1	Land	P1a	Land use coefficient
	P2	Energy	P2a	Non-renewable primary energy for construction, renovation and demolition of buildings
			P2b	Non-renewable energy for buildings in operations
	P3	Water	P3a	Infiltration surfaces and stormwater management
	P4	Biodiversity	P4a	Green surfaces
Sociocultural	P5	Well-being	P5a	Annual hours of overheating
			P5b	Interior noise level
			P5c	Average daylight factor
			P5d	Degree of electrosmog
			P5e	Degree of individualization of housing

			P5f	Quality of outdoor spaces
	P6	Security	P6a	Degree of security
	P7	Heritage	P7a	Degree of enhancement of heritage
	P8	Diversity	P8a	Degree of functional mix
			P8b	Potential of social diversity
			P8c	Degree of universal access
Economy	P9	Direct costs	P9a	Investment costs
			P9b	Gross rental yield
	P10	Indirect costs	P10a	Annual operating costs
	P11	External costs	P11a	External costs
	P12	Flexibility	P12a	Degree of flexibility of buildings

Each indicator is developed in a synthetic datasheet that includes all necessary informations to perform an assessment. As examples, the datasheet of two indicators assessing the environmental dimension of UWRP **are illustrated in Table 3** and **Table 4,** respectively C1c - "Tying status with soft mobility network" and P1a - "Land use coefficient". In an attempt to be representative of the variety of assessment methods, one addresses the context and uses qualitative values while the second refers to the project with quantitative measurements. The reference values are assigned in this case relatively to the Swiss context since the test application was carried out on an ongoing project in this country.

Table 3. Datasheet of the indicator C1c

Indicator	C1c Tying status with soft mobility networks
Definition	Intensity of connection to different networks for pedestrians and bicycles
Evaluation mode	Analysis of the number and quality of the various links
Measurement unit	Qualitative scale (from 0 to 5)
V_L (Limit Value)	Level 2 (in 5) The project is characterized by a relatively weak consideration of soft mobility and has connections only in two distinct directions
V_A (Average Value)	Level 3 (in 5) The project is characterized by a moderate consideration of soft mobility and has connections in three distinct directions
V_T (Target Value)	Level 4 (in 5) The project provides an important consideration of soft mobility and has connections in three distinct directions
V_B (Best Practice Value)	Level 5 (in 5) The project includes a systematic consideration of soft mobility (many specific devices) and has connections in four distinct directions
Data source	Plan and project guidelines

Table 4. Datasheet of the indicator P1a

Indicator	P1a Land use coefficient
Definition	Ratio of gross floor area and the area of land
Evaluation mode	Measurement of surfaces considered from the project plans.
Measurement unit	Quantitative scale
V_L (Limit Value)	0.5 (Limit to ensure public transport offer)
V_A (Average Value)	1.0
V_T (Target Value)	1.5
V_B (Best Practice Value)	2.0 (Density of central areas – Switzerland)
Data source	Project plan and cadastral data of the land

Test application

The Ecoparc neighborhood consists in the regeneration of an urban wasteland of about 4 hectares located in Neuchâtel, Switzerland. The triggering of the regeneration process dates back to 1989; since then, Bauart Architects and Planners Ltd is in charge of developing the project. The latter involves the creation of a new dense urban center based on a mix of functions (housing, offices and educational buildings), combining new constructions with transformation of old industrial buildings. Ecoparc is committed to a sustainable development approach. The project represents the inherent complexity of this type of operation (multiple stages of development, many actors involved, etc.) (Rey, 2002). The status of Ecoparc at the time of the assessment is an intermediate stage typical of UWRP **(Figure 1)**.

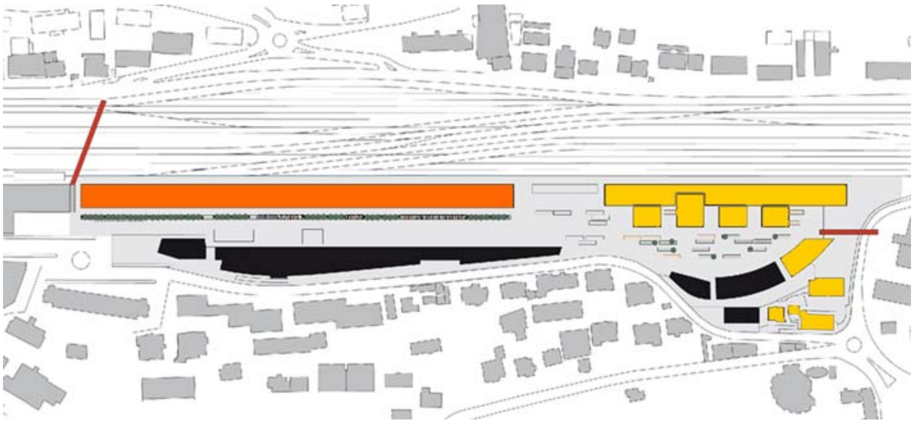

Figure 1. Site plan of Ecoparc at assessment. In black, buildings in operation. In yellow, buildings in execution phase. In orange, buildings in design phase. (Bauart document, 2005)

For the sake of complete verification, all indicators with available reference values were evaluated during the test application, including those that were not subject to particular attention. To integrate the results in the project dynamics - in accordance with the principles of monitoring - a bar chart histogram that follows the entire design process is used for each type of criteria. This paper exposes in **Figure 2 and Figure 3** the results of the two indicators presented in Table 3 and 4.

The project of Ecoparc includes a connection to pedestrian/bicycle networks in the four cardinal directions. In this sense, it tends to tie links that did not previously exist and increases the space reserved for pedestrian / bicycle along the main street. Expected final value corresponds to the target value V_T.

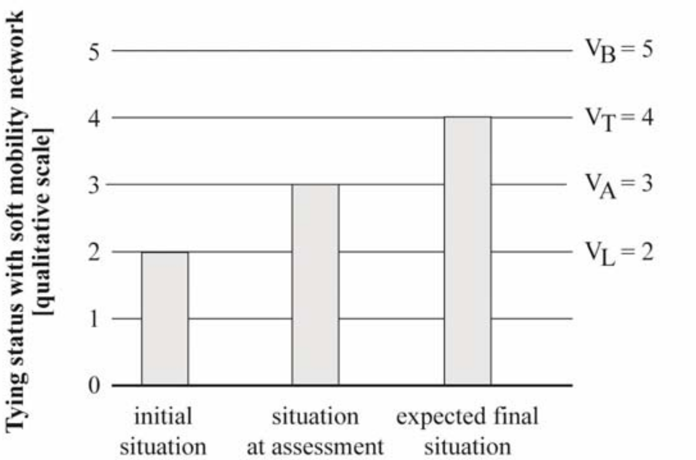

Figure 2. Test-application: evaluation of indicator C1c (Tying status with soft mobility network).

Ecoparc is characterized by an "optimal density" that simultaneously combines a quantitative contribution to urban regeneration and creates a neighborhood that takes into account the qualitative characteristics of the site. The expected final situation is 2.11 slightly above the Best Practice value V_B.

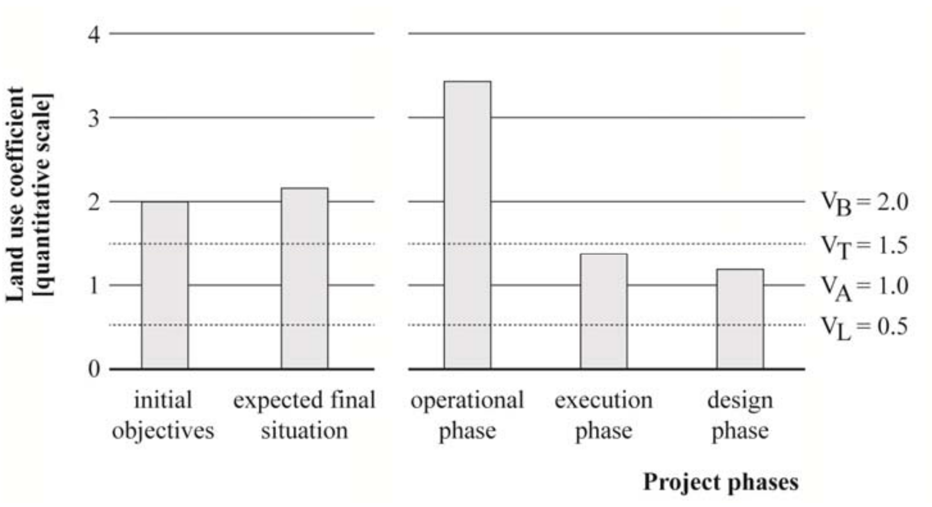

Figure 3. Test-application: evaluation of indicator P1a (Degree of flexibility of buildings).

VALIDATION OF THE INDICATOR SYSTEM

The test application has resulted in a real and iterative verification of the practical relevance of the methodology developed by SIPRIUS. It has proven that the indicator system is operational and can be used to assess both types of indicators. **Table 5** shows the results for the expected final situation of Ecoparc. In general, the evaluation has confirmed that Ecoparc falls significantly in a sustainable development approach. Indeed, the vast majority of indicators provides an expected final situation that meets the objectives **as shown in Table 5**. In that sense, the indicator system has contributed to raise awareness about various aspects of sustainability within the project.

Table 5. Test application: distributions of indicators based on the values obtained for the expected final situation in respect of the initial situation and the reference values.

Status	Context	Project
Number of indicators evaluated	19	19
Expected final situation greater than or equal to the objectives	16 (84%)	19 (100%)
Expected final situation greater than or equal to V_L	19 (100%)	19 (100%)
Expected final situation greater than or equal to V_A	17 (89%)	18 (95%)
Expected final situation greater than or equal to V_T	13 (69%)	14 (74%)
Expected final situation greater than or equal to V_B	8 (42%)	2 (11%)

In addition, the test application showed that SIPRIUS takes into account the requirements for a holistic evaluation of UWRP: it includes global quality and is adapted to the specificities of urban wastelands. Moreover, the graphical representation of the results helps to visualize the multiple phases of the project and the determination of reference values as "level of performance". In this sense, it sets basis to project monitoring by aiming at a greater sustainability. These complementary aspects validate that a relevant operational indicator system can be developed to suit the needs of UWRP for an integration of sustainability issues in the design process.

Toward an operational monitoring tool

To concretize sustainability targets, their integration into the project dynamics of urban wasteland regeneration and their continuous follow-up is an essential condition. The indicator system SIPRIUS contributes to this objective. It highlights the strengths and weaknesses of the project and feeds interactions amongst planners and decision makers. It also contributes to the transmission of results to audiences from various perspectives.

Nevertheless, its use depends primarily on the involvement and motivation of the stakeholders. Thus, the adaptation and transposition into a digital device in order to make a fully operational monitoring tool applicable to a multitude of regeneration projects would concretely facilitate the integration of sustainability in UWRP. Further work will be carried out in order to reach this objective, and will be the subject of future publications.

CONCLUSION

Three successive stages - identification of criteria, indicators and reference values - led to the creation of the operational indicator system SIPRIUS. The creation of the indicator system was done in parallel to the completion of a comprehensive test application. SIPRIUS meets the requirements of a search of global quality, is adapted to the specificities of UWRP and includes monitoring principles. The test application demonstrates that the indicator system is operational and contributes to integrate sustainability into the design process of the project. A transposition toward a digital monitoring tool in order to facilitate evaluation of diverse UWRP is suggested. Research is moving in this direction.

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A simplified Approach to integrate Energy Calculations in the Life Cycle Assessment of Neighbourhoods

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ABSTRACT

Life Cycle Assessment (LCA) is a method which can be used to effectively evaluate and optimize the environmental impact of the built environment. However, when carrying out an LCA on the neighbourhood scale, estimating the energy consumption in buildings is problematic because most energy simulation tools require a lot of input data, which are not available in the master planning stage. This paper proposes a simplified approach to evaluate the heating energy consumption in neighbourhoods, taking into account the neighbourhood layout and shading caused by interacting buildings. The proposed approach, which is implemented for the Belgian context, is a refinement of the existing Equivalent Degree Day (EDD) method, by including results from both semi-dynamic and dynamic solar gain calculations. To illustrate this new approach, a parametric neighbourhood model is developed, linked to the energy simulation software EnergyPlus and LCA calculations. Simulations of a medium-density urban block reveal substantial differences in heating energy consumption, depending on shading patterns, confirming the importance of integrating simple but reliable energy calculations in neighbourhood LCA.

1. INTRODUCTION AND OBJECTIVES

In order to move towards a more sustainable built environment, new urban developments need to be planned and organized differently. As shown in previous studies (Trigaux, Allacker, & De Troyer, 2014) (Herfray, 2012), life cycle assessment (LCA) is a method which can be used to effectively evaluate and optimize the environmental impact of buildings and neighbourhoods. However, when carrying out an LCA on the neighbourhood scale, estimating the energy consumption in buildings is problematic, especially for passive and low energy design.

To date, most building energy simulation tools require a large amout of data, which is unavailable in the early stage of the design process. Although technical aspects are often not considered during the master planning stage, decisions related to the neighbourhood layout, building compactness and solar shading can also affect the heating energy demand importantly. Therefore a fast but reliable energy calculation method is needed, taking those aspects into account.

This paper proposes a simplified approach to evaluate the heating energy consumption in neighbourhoods during the master planning stage; which can be integrated in an LCA study. The proposed approach is based on the Equivalent Degree Day (EDD) method (Diensten voor de programmatie van het wetenschapsbeleid, 1984), giving a first estimation of the heating energy demand. In order to accurately consider the impact of solar gains and shading caused by interacting buildings, the original method is refined, using results from both semi-dynamic and dynamic solar gain calculations.

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This new method, further referred to as dynamic Equivalent Degree Day method, is illustrated based on a parametric neighbourhood model linked to the energy simulation software EnergyPlus (U.S Department of Energy, n.d.). The energy calculations are moreover integrated in a broader LCA study.

In the subsequent section the methodological aspects are described, focussing on the Dynamic EDD method and the LCA. In section 3 the parametric model is described and used to analyse the energy consumption and life cycle environmental impact of a medium-density urban block. Conclusions and recommendations are drawn in the final section.

2. METHODOLOGY

From the Degree Day method to the dynamic Equivalent Degree Day method

The Degree Day (DD) method is an existing method to estimate heating requirements in buildings, when no layout decisions are taken. The basic assumption is that the yearly heating demand at a specific location is proportional to the number of DD (°d) at that location (Diensten voor de programmatie van het wetenschapsbeleid, 1984a). For each day of the heating season, the difference between the average indoor temperature (T_i) and average outdoor temperature (T_e) is calculated. The sum of all these daily temperature differences over the whole heating season results in the number of DD. This is illustrated in **Figure 1** with the DD 15/18 for the temperate Belgian climate. In this specific case it is assumed that no heating is required when the daily average outdoor temperature is higher than 15°. Furthermore, a fixed average indoor temperature of 18°C is considered. In **Figure 1**, the number of DD is represented by the surface enclosed by the indoor and outdoor temperature curves and the lines delimiting the heating season. For practical reasons, this surface is approximated using monthly average outdoor temperatures, as illustrated by the hatched surface in **Figure 1**. In this paper, 2738°d are calculated as representative for the Belgian climate, based on the EnergyPlus test reference year for Brussels.

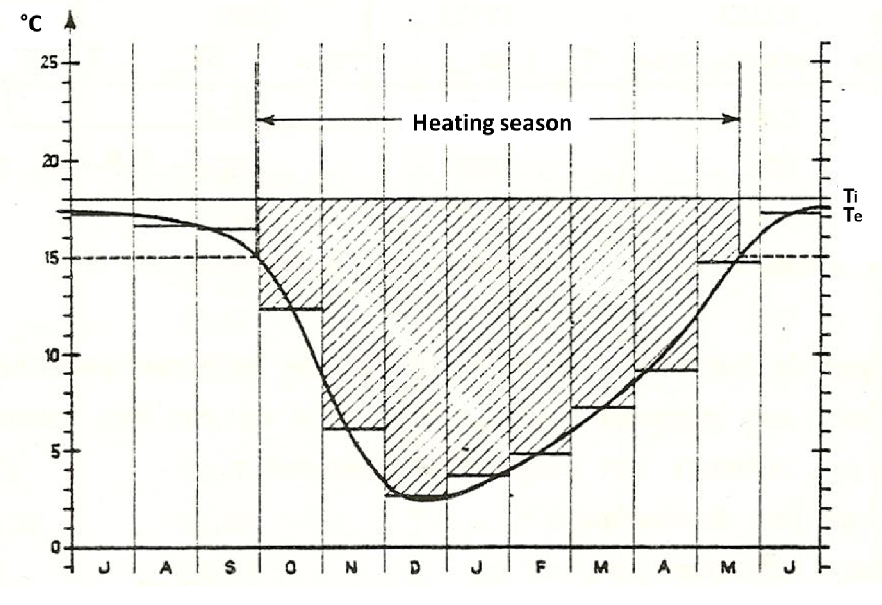

Figure 1 DD 15/18 for the temperate Belgian climate (Diensten voor de programmatie van het wetenschapsbeleid, 1984a, p.33).

Based on the number of DD, the heating energy demand (Q_j) is estimated using **Formula 1** (Diensten voor de programmatie van het wetenschapsbeleid, 1984b, p.39), which includes the impact of heat transmission losses through the building skin and heat ventilation losses:

$$Q_j = (U_m * S + V * n * 0.36) * 3600 * 24 * °d \qquad (1)$$

With:

- U_m = average heat transfer coefficient (W/m²K)
- S = heat loss surface (m²)
- V = inside building volume (m³)
- n = air change per hour (1/h)
- °d = number of Degree Days

The Equivalent Degree Day (EDD) method is a refinement of the DD method, as the latter often leads to an overestimation of the heating demand (Diensten voor de programmatie van het wetenschapsbeleid, 1984b). Internal heat gains (resulting from people, electric devices and artificial lighting) and solar gains, which are not considered in the DD method, often result in a reduction of the heating demand, especially in well-insulated buildings. For this reason, the DD method was refined by defining EDD (eq d°). EDD (**Figure 2**) are calculated based on two temperature curves: the temperature curve of no more heating (T_{NH}) and the temperature curve without heating (T_{WH}). The first one (T_{NH}) is defined as the indoor temperature above which no heating is required. This T_{NH} is lower than the original indoor temperature of 18°C, since the internal gains will be sufficient to compensate the heat losses. The second temperature curve (T_{WH}) is the increased indoor temperature, resulting from solar gains, when the building is not heated and not occupied.

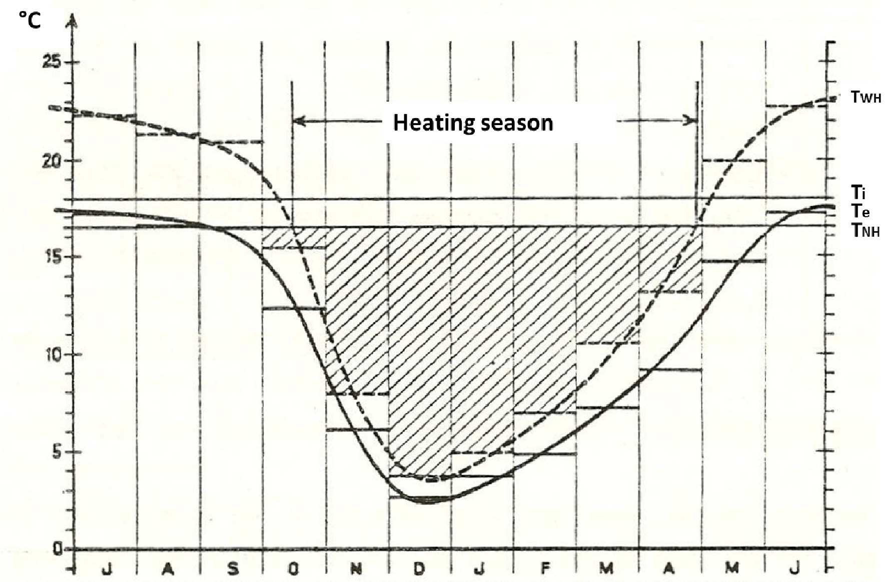

Figure 2 Equivalent Degree Days 15/18 for the temperate Belgian climate (Diensten voor de programmatie van het wetenschapsbeleid, 1984a, p.36)).

The T_{WH} is hence calculated, based on the useful solar gains in a building. These solar gains can be estimated by using several approaches, ranging from static to dynamic simulations. In the original EDD method, a static approach was followed, based on average solar radiation data for two characteristic months of the year (respectively March and December) (Diensten voor de programmatie van het wetenschapsbeleid, 1984b). In previous research, Allacker (Allacker, 2010) determined an average of 1200 eq d° for residential buildings in the Belgian context, based on an analysis of two dwelling types, and for several insulation levels. The calculation of this average EDD was based on the Flemish Energy Performance of Buildings (EPB) regulation (Flemish Government, 2005). This estimation is used in the analysis (section 3) as a reference base for the more dynamic calculations (see next paragraph).

This paper proposes a new method, the dynamic Equivalent Degree Day method, based on two more dynamic solar gain calculations. Firstly, a semi-dynamic calculation was made based on the Flemish EPB regulation (Flemish Government, 2005). In this first approach, a characteristic day of each month is considered and shading patterns, resulting from neighbouring buildings, trees, sheds or side walls, are approximated by defining a set of obstruction and overhang angles per window. For each window those angles are then projected on the visible part of the sky dome to calculate the reduction in direct solar radiation, compared to unshaded conditions. As illustrated in **Figure 3** for a dwelling in a rectangular urban block, this approximation can lead to an overestimation of shading patterns and thus lower solar gains than in reality. Secondly, a dynamic energy caculation, using the the software EnergyPlus, was made to calculate the indoor temperature without heating (T_{WH}). In this second approach, solar gains are simulated, based on detailed reflection algorithms, for all days of a test reference year. The results of both approaches were compared and are discussed in the subsequent section.

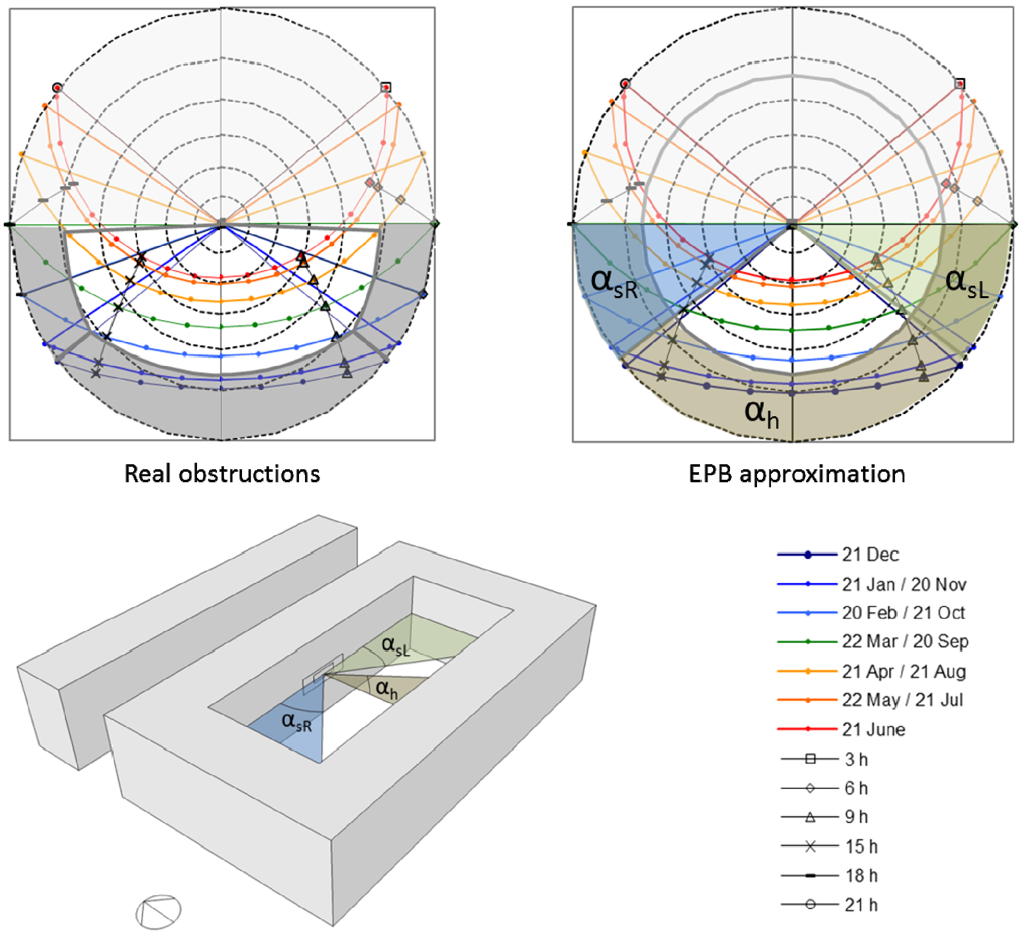

Figure 3 Stereographic projection of shading obstructions for a window in a rectangular urban block. Real obstructions (left) are compared with the EPB approximation (right).

LCA method

The environmental impact assessment in this paper is based on an existing LCA method developed within the MMG ("Milieugerelateerde Materiaalprestatie van Gebouwelementen") research project, commissioned by the Public Waste Agency of Flanders (OVAM) (Allacker et al., 2013). This method, specific for the Belgian context, evaluates the environmental performance of building elements. Besides individual impact indicators, the MMG method allows to assess the environmental impact based on an aggregated indicator, expressed in environmental costs (i.e. external costs caused by environmental impacts).

Based on the MMG database of building elements, we developed a simple tool to assess the environmental impact of buildings and neighbourhoods. Using a limited number of input data, building elements can be combined to buildings, which in turn can be clustered to a neighbourhood model. In this paper, this tool is applied for the LCA calculations.

3. SIMULATION RESULTS

Parametric model

To illustrate the methodology, we defined a parametric neighbourhood model of rectangular urban blocks (**Figure 4**), linked to the EnergyPlus software. Although many geometric variants are possible, we focus on a medium-density urban block in order to evaluate the impact of shading interactions. This block consists of 15 m high buildings around a courtyard of 50m by 20m and is separated from other blocks by 10m wide streets. In this paper, only one side of the urban block with a north-south orientation is analysed (**Figure 4**). However, the other sides could be evaluated in a similar way. For the simulations, the building is subdivided in a grid of 25 dwellings of 100m². The glazed surfaces, which are assumed to be 25% of the façades, are approximated by two big windows, oriented respectively to the street and courtyard. Futhermore, building elements, fulfilling the low energy standard, are defined, using elements from the MMG database.

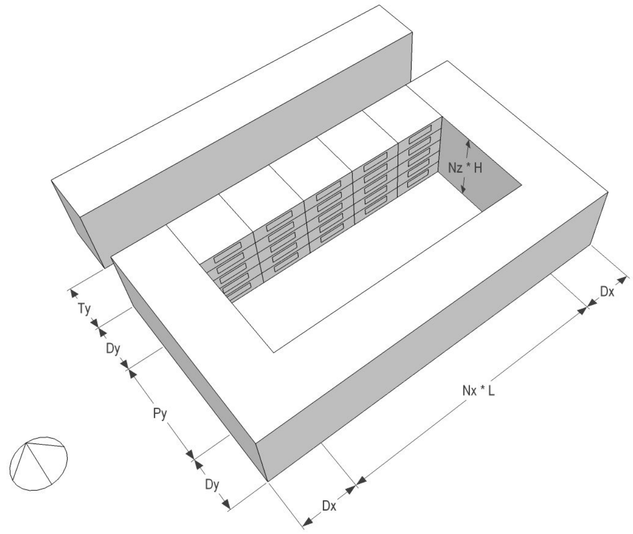

Figure 4 Parametric neighbourhood model.

Dynamic EDD calculations

For the 25 dwellings the dynamic EDD are calculated using both the EnergyPlus and EPB approach. In order to analyse the impact of shading, each dwelling is simulated both in shaded and unshaded conditions. The results are shown in **Figure 5** and expressed in percentage compared to a reference dwelling in unshaded conditions**.**

When looking at the results for the unshaded conditions, the impact of internal and solar gains is clearly noticeable in the number of EDD. As an example, the reference dwelling is characterized by 1176 eq°d based on the EnergyPlus approach (1173 eq°d based on the EPB approach), which means a reduction of about 60% of the estimated heating requirements, compared to the standard DD method (2738 °d). Furthermore, higher EDD are calculated for the dwellings located under the roof and on the ground floor. This is a consequence of the higher heat transmission losses through the building skin, resulting in lower heat gain utilization. Regarding the comparison between the semi-dynamic and dynamic approach, similar results were found, except for the dwellings on the ground floor. In this case the simplified ground heat transfer calculation in EPB seems to overestimate the heat losses via the ground.

Concerning the results in shaded conditions, an important increase of the EDD is noticed, compared to the unshaded conditions. For the EnergyPlus approach, this increase ranges from about 5% for the dwellings under the roof to about 35% for the dwellings on the ground floor. Similar results were found for the EPB approach but with bigger differences between the shaded and unshaded conditions. This is a direct consequence of the EPB approximation based on obstruction and overhang angles (**Figure 3**).

Eq d° in unshaded conditions - EnergyPlus

121%	121%	121%	121%	121%
100%	100%	100%	100%	100%
100%	100%	100%	100%	100%
100%	100%	100%	100%	100%
109%	110%	110%	110%	109%

Eq d° in unshaded conditions - EPB

121%	121%	121%	121%	121%
100%	100%	100%	100%	100%
100%	100%	100%	100%	100%
100%	100%	100%	100%	100%
123%	123%	123%	123%	123%

Eq d° in shaded conditions - EnergyPlus

125%	124%	124%	124%	125%
111%	107%	107%	107%	111%
119%	114%	113%	114%	119%
128%	125%	124%	124%	128%
143%	140%	140%	140%	143%

Eq d° in shaded conditions - EPB

131%	130%	129%	130%	131%
117%	116%	115%	116%	117%
125%	124%	123%	124%	125%
130%	129%	129%	129%	130%
150%	151%	150%	151%	150%

Figure 5 EDD of the analysed dwellings in shaded and unshaded conditions, based on the EnergyPlus and EPB approach. The results are projected on the courtyard façade and expressed in percentage, compared to a reference dwelling in unshaded conditions (indicated by the black frame).

Environmental impact calculations

Based on the calculated EDD, the heating energy consumption of the 25 dwellings can be estimated and summed up over the whole building. This total heating energy consumption can then be used as input in the LCA calculation tool. The results of the environmental impact assessment are shown in **Figure 6**, with a distinction between the impact of building materials and heating energy use. Six models to estimate the energy consumption are compared, including the standard DD method (2738°d), the static EDD using the average of 1200 eq°d and the dynamic EDD based on EnergyPlus and EPB (both for unshaded and shaded conditions).

Firstly, the results show a significant overestimation of the building environmental impact, when applying the standard DD method: the life cycle environmental costs are about 30% higher, compared to the EnergyPlus model for shaded conditions. Secondly, an average of 1200 eq°d seems a good approximation for the unshaded conditions. However, a difference of about 5% in life cycle environmental costs and about 15% in heating environmental cost was noticed between the shaded and unshaded conditions. It is expected that this difference could even be bigger, when using high-insulated passive building elements, increasing the internal utilization of solar gains. Therefore, a dynamic EDD calculation based on EPB or EnergyPlus is recommended, especially in dense neighbourhoods. Finally, only small life cycle impact differences are found between the EPB and EnergyPlus approach (from about 1% to 2% for respectively the shaded and unshaded conditions). The semi-dynamic calculation hence seems (for this case study) a good approximation for the more complex dynamic calculation.

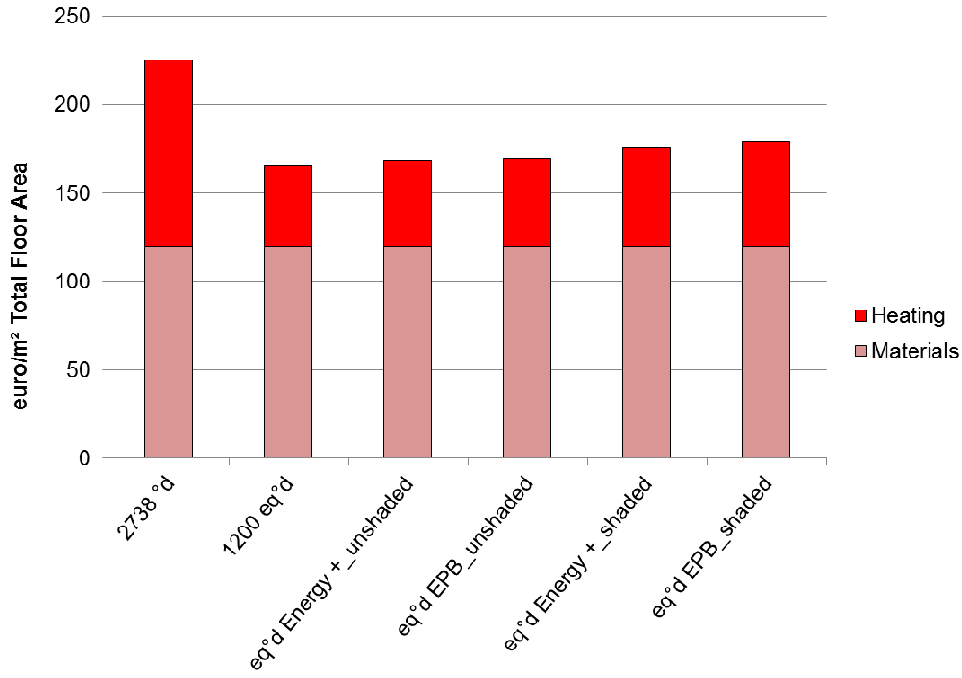

Figure 6 Building life cycle environmental cost calculated using 6 heating energy calculation methods: standard DD (2738°d), static EDD (1200 eq°d) and dynamic EDD based on EnergyPlus and EPB (for unshaded and shaded conditions).

4. CONCLUSIONS

In this paper, a simplified approach is developed to estimate the heating energy consumption in the context of neighbourhood LCA. The existing EDD method is refined by including results from both semi-dynamic and dynamic solar gain calculations. Simulations of a medium-density urban block reveal substantial heating energy demand differences between shaded and unshaded conditions, stressing the importance of more dynamic solar gain calculations, especially for dense urban developments. Nevertheless, the static EDD (1200 eq d°) seems to be a good approximation, if supplemented with dynamic EDD for the most critical housing units. Furthermore, because of limited life cycle impact differences, compared to a full dynamic simulation, the semi-dynamic EDD, based on EPB, seems to be a valuable method for integration in an LCA tool. However, to avoid an overestimation of shading patterns, it is recommended to refine the EPB approximation by using a variable obstruction angle for different orientations.

Concerning further research, we recommend validating the above conclusions by simulating more case studies and variations in urban block geometry. As the number of Equivalent Degree Days depends on the building insulation level, the influence of this parameter should be analysed in detail, especially for high-insulated passive buidlings. Finally, as the subdivision of each building block in constituting dwellings increases the simulation time, we recommend investigating whether simulations can be limited to a set of representative dwellings that could be used for interpolations.

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SméO, a sustainability assessment tool targeting the 2000 Watts society

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ABSTRACT

Switzerland has adopted the concept of the 2000 Watts society as a long term target, with an intermediate objective for 2050: a reduction of the average energy consumption per person from 6300 to 3500 watts, including a maximum of 2000 watts of non-renewable energy. Following this concept, the SIA (Swiss Society of Engineers and Architects) has developed energy consumption targets for the built environment: embedded energy of materials, operating energy (heating, domestic hot water, electricity, air conditioning) and mobility.

In order to achieve these targets in all projects of new buildings or renovations, the Canton of Vaud and the City of Lausanne have adopted and included them into SméO, a decision-making tool for the sustainability assessment of building or neighborhood projects. This paper presents the methodology applied by the tool for the energy assessment. The methodology is entirely based on building standards and norms for all the domains where these exist. In the other cases, assumptions have been made.

The evaluation follows the entire project. For the first stages of the project where energy calculations have not been done yet, the tool offers default values for energy consumption, mobility and embedded energy based on the characteristics of the project. Hence, the project can be optimized from the very beginning of the process. SméO being a free web platform, results can be shown and easily communicated to all stakeholders.

Keywords: Assessment tool, 2000 Watts society, energy targets, project optimization, communication

INTRODUCTION

Energy consumption of the built environment represents 31% of the total energy consumption in the world (GEA, 2012), and 47% in Switzerland. Hence, energy efficiency in buildings can have a great impact on the path toward a sustainable energy system. The Swiss Federal Institutes of Technology have developed the "2000 Watts society" concept (Novatlantis, Swissenergy, & SIA, 2011), which states that by 2150, our energy consumption should be reduced from 6300 to 2000 watts, among which 75% renewable energies, and greenhouse emissions reduced from 8.6 to 1 tone/pers.yr. This concept has been adopted by the Swiss government to face the energy challenge.

The 2000 Watts objective includes all energy consuming sectors: industry, alimentation, services, transport, building, etc. The SIA (Swiss Society of Engineers and Architects) has developed energy targets for new buildings and renovations. The technical report SIA 2040 "SIA Energy Efficiency Path" (SIA, 2011) establishes the energy consumption limits for embedded energy, operating energy and mobility to reach the global intermediate target of 440 MJ/m^2 for 2050. As this goal represents the mean energy consumption for 2050 for the built environment, all new buildings and renovations should at least reach this target to really progress toward this objective. Hence, project managers need to know the performance of their project and adapt it to the targets. Assessment tools are then needed to do so, to inform stakeholders and to communicate with experts and investors.

BUILDING PERFORMANCE ASSESSMENT TOOLS

A high number of energy assessment tools for buildings have been developed (Annex31, International Energy Agency, & Energy Conservation in Buildings and Community Systems, 2001; Haapio & Viitaniemi, 2008). For its part, The SIA has developed a tool to calculate the energy consumption for embedded energy, operating energy and mobility for buildings (new and refurbished) (SIA, 2013). In addition, the Federal Office of Energy (OFEN) has developed a tool to evaluate neighborhoods (OFEN, 2013), also in regards with the 2000 Watts society.

Nevertheless, the design process is guided by a high number of objectives such as comfort, return on investment, health, etc. Energy is an important criterion but other aspects are also relevant. Energy efficiency without comfort being meaningless, the optimal solution needs to be found. Several tools consider the fact that the built environment is affected by economic, social and environmental aspects, pursuing a holistic and sustainable vision of building projects. In Switzerland there are two main methods: SméO and SNBS. SméO is a decision-making method, a free web platform based program (www.smeo.ch) which allows stakeholders to assess the sustainability of their projects, to compare scenarios and to communicate results. It has been developed by the Canton of Vaud and the City of Lausanne in 2009. The Sustainable Construction Network Switzerland (NNBS) has developed in 2013 the SNBS: the Swiss standard for sustainable buildings. The tool is presented as an excel sheet for the calculations of different indicators (SNBS, 2013), therefore the use of the tool is less accessible to non-experts. On the path toward the 2000 Watts society, a decision-making tool accessible to a broad public would be necessary to help decision-makers optimize their project through the whole development process. In this sense, SméO is a decision-making tool, user-friendly, adapted for non-experts (Roulet & Liman, 2009). It is the optimal instrument to enable the implementation of the 2000 Watts society in the built environment.

SMEO & THE "2000 WATTS SOCIETY"

SméO, sustainability assessment tool

SméO provides an indicator system assessing sustainability at the different stages of a project, from the first idea to the construction and usage of buildings and neighborhoods. It considers the entire life cycle of the building, being renovated or built. Following the SIA 112/1 "Sustainable construction – Building" recommendation, the domains evaluated are: Governance, Resources, Site and architecture, Community, Cost and finances, Land and landscape, Infrastructures, Building concept, Materials, Worksite management, Investment, Integration, Identity, Viability, Security, Comfort and health, Energy, Water and Waste, Return on investment, Technical equipment maintenance and deconstruction at the end of life. Each domain is evaluated by several indicators; these can be either quantitative or qualitative and they vary depending on the project's type and scale. The tool provides two or three thresholds (Riera Pérez & Rey, 2013):

1. Limit value: boundary between acceptable (yellow), and unacceptable, due to incompatibilities with either common practice or with legal requirement (red).
2. Target value: boundary between acceptable and best practice (green).
3. Veto (black), only for some indicators which can have a negative impact on the entire project

Results of each indicator are aggregated according to the Hermione methodology (Flourentzou, 2001).

Each user has its own account where she/he can register and assess several projects, as shown in figure 1**.** Projects can be shared with other users. Project with titles in blue have been shared with other users. The ones in red correspond to projects created by another user and shared with the user of this account. Column A shows different functions related to the project: "Create a new project", "My projects", "Share projects" and "Energy prices". This last function is used to calculate the cost of

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the operating energy per year. For each project, one has access to the information in line B: First, "General characteristics". Second, the "project analysis" showing the assessment of the different domains. Third, "Complete results" presenting the assessment for all the stages of the project, the economic impact and the environmental impact, including the performance of the project with respect to the 2000 Watts society framework are communicated. Finally, C is used to compare different projects.

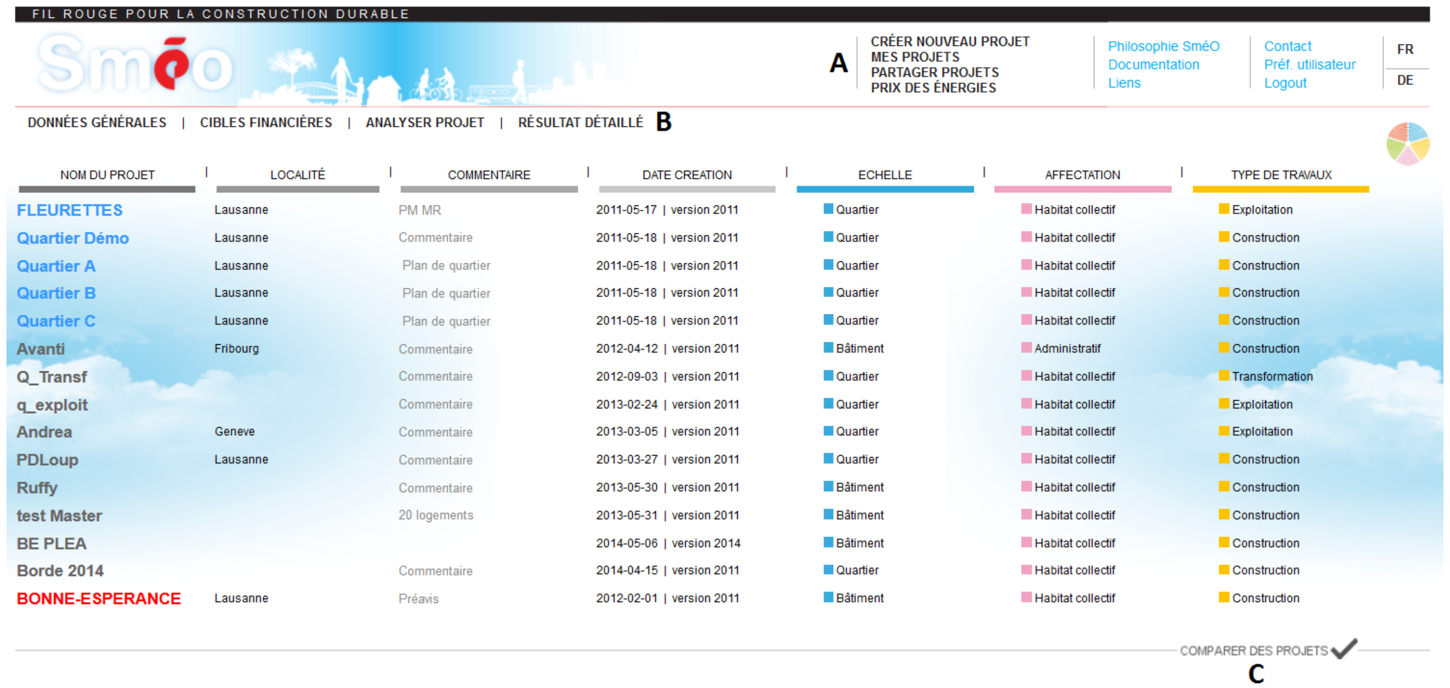

Figure 1 SméO user interface

2000 Watts society targets

The 2000 Watts targets for the built environment developed by the SIA (table 1) marry the ambition of a society to reduce its energy consumption to 1/3 and the technical feasibility (Heeren, Wallbaum, & Jakob, 2012).

Table 1. 2000 Watts society targets for 2050, by SIA 2040

	NRE (MJ/m^2 ERA yr.)			GWP ($KgCO_2$ eq./m^2 ERA yr.)		
	Embedded	Operating	Mobility	Embedded	Operating	Mobility
New	110	200	130	8.5	2.5	5.5
Renovation	60	250	130	5.0	5.0	5.5

Method applied by SméO for the assessment of the 2000 Watts society

The program calculates NRE (Non-Renewable Energy), GWP (Global Warming Power) and also UBP (Eco-points) per m^2 ERA: Energy Reference Area, from the first stages of the project, even if the 2000 Watts society doesn't include UBP. The methods to calculate the embedded energy, operating energy and mobility are exposed below.

Embedded energy. The method applied is based on the technical report SIA 2032 "The buildings' embedded energy", which calculates the energy needed for all components, considering their lifecycle and a time period of 60 years to write off the total embedded energy of the building. The method differentiates two sectors: heated areas and non-heated areas. The main features of the building required for the calculations are the ones in Table 2, for which the tool suggests several default values.

Table 2. Considered components in the calculation of the embedded energy

Heated areas	Non-heated areas
Façade	Excavated volume
Lower and intermediate slabs	Basement slab
Roof	Bearing walls and partitions
Walls	Intermediate slabs
Windows	
Window frames	
Level of technical equipment	

The environmental impacts (NRE, GWP, UBP) per m^2 for each option are calculated by a LCA (Life Cycle Assessment) program: Lesosai (http://www.lesosai.com) and Eco-Bat (http://ecobat.heig-vd.ch). There are two levels of technical equipment: high or low. The first level corresponds to a high-tech building. The second level corresponds to a standard building based on legal requirements.

Target values defined by the SIA 2040 deal with households, economic activities and schools buildings. The values for the other uses have been adapted: the target for economic activities is also applied for commercial surfaces, hospitals and industries, and the target for households to stocks, sports facilities, swimming pools and space for events. These embedded energy values refers to the building. Special technical equipment for swimming pools or hospitals should be evaluated separately.

Operating energy. The impact of the operating energy is the result of the consumption and the energy production system for heating, residential hot water, electricity and cooling. The conversion factor from final energy to NRE, GWP and UBP are drawn from the KBOB LCA data (KBOB, 2012).

For the first stages of the project SméO estimates the impact based on the targeted energy standard:

1. Legal requirements
2. Minergie® standard or equivalent
3. Minergie-P® standard (2000 Watts society compatible)

The tool calculates the energy demand following the SIA norm 380/1: "Thermal energy in buildings" which adapts to the different surface uses: residential, commercial, etc. This normative energy demand is reduced depending on the energy standard targeted. The energy production is also adapted to the standard. For Minergie-P® the heat production proposed by the tool is wood-pellets. For the Minergie® standard, production is through a heat pump, with 30% of solar thermal for domestic hot water. Finally, for the application of the legal requirements, the production system is a condensing gas boiler. The electricity source is slightly adapted: projects in accordance with legal requests are supplied by Swiss electricity network (MIX Swiss). For Minergie® and Minerige-P® projects, 20% and 30% of photovoltaic cells production is added, respectively.

For the operating energy, SméO evaluates not only NRE and GWP but also the final energy consumption for heating (see table 3) and the percentage of renewable energy for heating, domestic hot water and electricity of new buildings, see figure 2**.** The operating energy assessment for renovation or transformation projects is based only on the total NRE and GWP because existing building are very diverse, with specific objectives for each energy use. The percentage of renewable energy must be more important since the consumption increases in order to reach the NRE target. The increase in energy consumption is relative to the normative value: $Q_{h,li}$, Q_{ww} and Q_{el} for heating, domestic hot water and electricity respectively, calculated by the SIA 380/1 norm. $Q_{h,eff}$ is the energy need for heating taking into account the energy recovery.

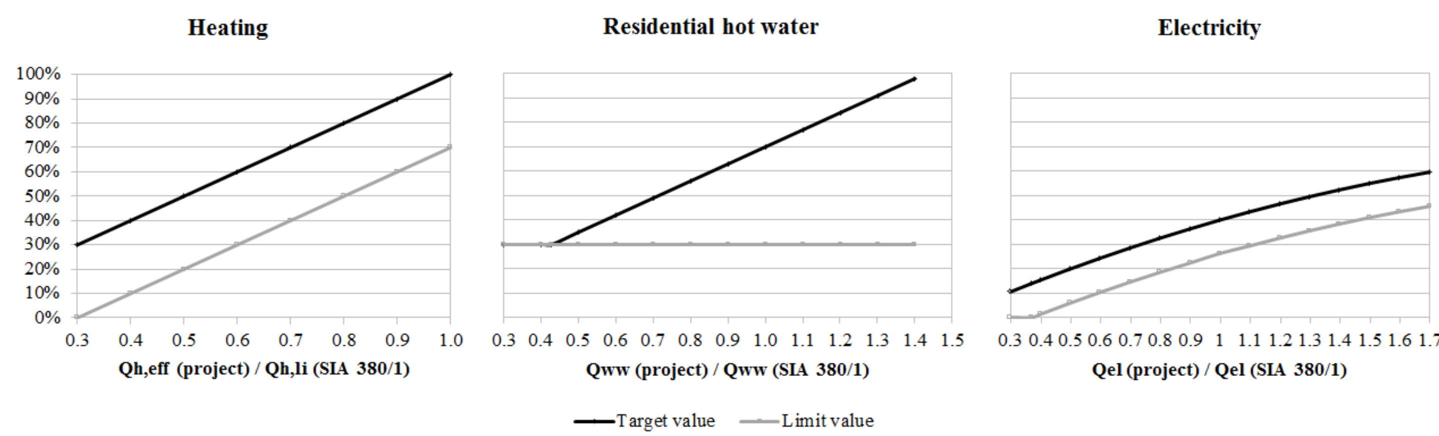

Figure 2 Part of renewable energy limit values for operating energy

Table 3. Assessment of Q_h. (Q_h : final energy for heating, $Q_{h,li}$: legal value fixed by the SIA 380/1 norm)

Assessment limits	New buildings	Renovated buildings
Best practice (green)	$Q_h < 0.6\ Q_{h,li}$	$Q_h < 0.8\ Q_{h,li}$
Acceptable (yellow)	$0.6\ Q_{h,li} < Q_h < 0.9\ Q_{h,li}$	$0.8\ Q_{h,li} < Q_h < Q_{h,li}$
Unacceptable (red)	$0.9\ Q_{h,li} < Q_h < Q_{h,li}$	$Q_{h,li} < Q_h < 1.1\ Q_{h,li}$
Veto (black)	$Q_{h,li} < Q_h$	$1.1\ Q_{h,li} < Q_h$

Mobility. The applied method is based on the technical report SIA 2039 "Mobility - Energy Consumption of Buildings according to their Location". The method weights the Swiss average energy consumption for mobility by several correction factors related to the context and facilities. "The correction factors are obtained from a statistical analysis of the federal micro-census of 2005 (OFS & ARE, 2007) and vary depending on the surface uses. They are:

1. Location: located in downtown/business area
2. Access and quality of public transport
3. Distance to a shopping center
4. Availability of a car
5. Availability of parking for cars and bikes
6. Availability of public transportation passes." (Riera Perez & Rey, 2013).

If users are identified, the SIA 2039 recommends a much precise calculation taking into account the distance and means of transport employed by the occupants.

The target values for the surface uses that are not included in the SIA 2040 have been defined by separating energy for employees and for visitors or customers. Employees' mobility is the one defined for economic activities in the SIA 2040. Visitors or customers' mobility have been taken from the mode of mobility (distance and mode of transportation) defined by the federal micro-census of 2005, differentiating mobility for shopping and for leisure. The assumption is that commercial activities generate the shopping type mobility. Restaurants, sport facilities and meeting spaces generate leisure type mobility. Finally hospitals generate the same mobility as an average inhabitant as we assume that patients going to the hospital go from home and return back home. The same energy reduction (energy saving in percentage of the Swiss mean value), is asked for all land use surfaces.

RESULTS

As a decision-making tool dealing with multi-disciplinary assessment, the communication of results is important. Figure 2 shows the graphics presenting the projects toward the 2000 Watts society. On the left side, total NRE and GWP graphs inform the user about the completion of the 2000 Watts target, corresponding to the green line. The two columns differentiate the actual impact with the one for 2050, considering technological improvements of vehicles. On the right side, the contribution of each energy use is detailed in order to help decision-makers focus on the bigger impact.

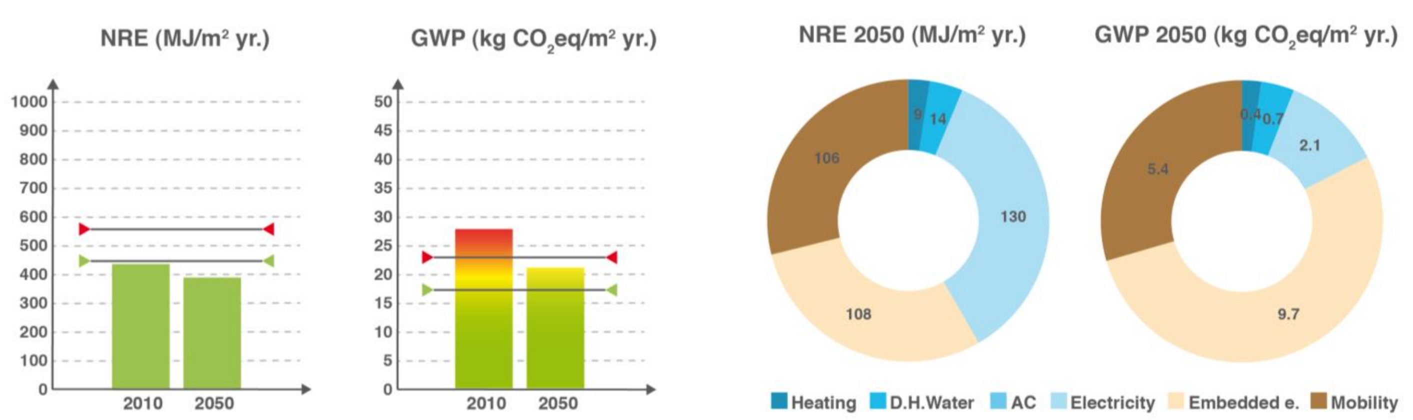

Figure 2 SméO results: 2000 Watts assessment and contribution of each energy use to the whole impact.

CONCLUSIVE DISCUSSION

Because SméO is intended to all project managers, the web page offers documentation presenting the calculation method, references and a user guide. A decision-making tool can be used in very different ways; results highly depend on the input data since no verification is done in comparison to a certification process. Thus, using a tool like SméO is judicious only if the project manager seeks a sustainable building development. Therefore, the tool presented is an instrument to contribute to the 2000 Watts society, but other ways need to be found to implement the energy reduction target such as modifying the energy legislation and urban planning regulations.

In Switzerland, the SIA has an important influence on the normative domain because of its capacity to promote innovative answers for new challenges. Since environmental, cultural and legal aspects change from one country to another, the method would need to be adapted prior to its use in a different context (Singh, Murty, Gupta, & Dikshit, 2012) in order to guide towards appropriate targets. Therefore, identifying the regional specific challenges, standards and solutions would be needed to adjust the tool.

The user of a building can highly influence the energy consumption and some papers have shown that going from 6000 Watts to 2000 Watts cannot be done without the contribution of the occupant behavior. Hence, new developments are necessary to follow the real energy consumption during the lifetime of buildings.

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AFFORDANCE OF THERMAL COMFORT THROUGH PASSIVE DESIGN: A Case Analysis on Effects of Ventilation, Shading, and Thermal Mass in Delhi

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ABSTRACT

As concomitants to developments and globalization, Indian modernism witnessed unprecedented socio-economic and lifestyle benefits on the one hand, and adaptation to high-energy habitats and lifestyle, and subsequent degradation of the native habitats milieu, on the other. Unlike compact traditional buildings or occupants' lifestyle, modern buildings and its inhabitants generate much heat. House-2 in Delhi by Morphogenesis, conceptualized as a 'porous' object with adequate thermal mass, is a radical re-interpretation of haveli[1] *typology to optimum plan forms to account for modern lifestyles and environmental imperatives. Thermal comfort is affected by the body's heat exchange with the climatic parameters, and engineering of conduction, convection, radiation of heat or cold through various effects of ventilation modes and air change rates, solar shading, and thermal mass envelopes are hypothesize to afford better indoor environment conditions, and thereby thermal comfort with low-energy. Solar Designer Ver.6 and Ecotect (2011) were used for analysis and simulations of the following cases: 1). House 2, As-built and light thermal mass with no shading, 2) 3 prototype rooms to check ventilation effects on glazing area, thermal mass, and insulation. The results are shown in 1) hourly indoor temperature fluctuation without air-conditioning and Discomfort Index, 2) annual heating and cooling load in a year. The analysis shows that Flex Vent mode was more energy efficient than Normal conditions without ventilation. While thermal comfort was not fully afforded for during summer, passive design in House 2, as-built, perform better than light thermal mass, and hence improved energy efficiency. Hypothetical case analysis shows insulation was most effective in both summer and winter for the hypothesis cases.*

INTRODUCTION

Affordance of thermal comfort mandates passive design techniques that account for low-energy imperatives during operations, such as: reduction in artificial lighting, heating or cooling, and innovative use of low embodied energy materials during construction. In India, housing and commercial sectors accounts for 29% of electricity consumption and rises at the rate of 8% annually. (Govt. of India Planning, 2011). The case study, House-2 in Delhi by Morphogenesis, was conceptualised as a platform to investigate two issues central to design today: the family as a social unit and the environment. The residence multitasks as a house for 3 generations, visitors, occasional cultural hub, and basement architecture studio. The house consists of overlapping spatial zones: private domain of the family, semi-private shared inter-generational spaces, and the public domain of the lobby, and offices. Located at coordinates: 28.5°N, 77.2°E, and 216m above mean sea level, House 2, through passive design techniques, attempts to respond to site limitations, and climate swings of a composite climate with maximum hot-dry 40-46°C DBT for about 2 and half months, followed by hot-humid period, and a minimum DBT of about 3-8°C in winter.

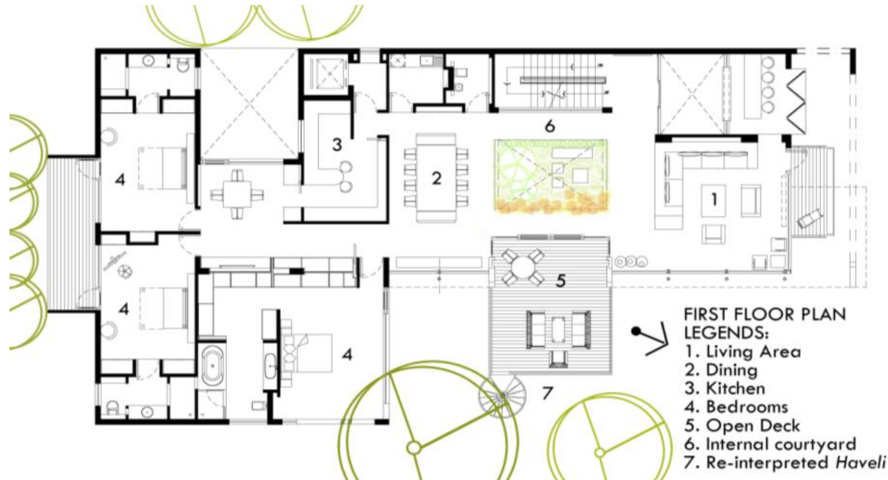
RESEARCH INTENT AND OBJECTIVES

The last few decades of Indian modernism, as concomitants to socio-economic developments, imported technology and praxis without context increase energy demands and degraded the native habitats milieu. Given the complex multi-functional needs of modern buildings, pragmatic re-interpretation of traditional passive techniques into contemporary design as a response to the socio-economic and low-energy imperatives becomes *avant garde*. In traditional architecture passive techniques, such as: *haveli*[1] provides solar shading, grass lawns and water bodies provides evaporative cooling; high thermal mass walls and roofs attenuates diurnal heat gain, and its high emissivity allows rapid cooling at night; and *Jaalis*[2] afforded privacy and airflow. (Ali, A. 2012). Historical references are: Taj Mahal, Red Fort's emperor's throne *diwan-e-khas*[3], *Agrasen ki Baoli*[4] step-well in CP, Delhi, etc. This paper aims to highlight effects of ventilation modes and air change rates, solar shading, and thermal mass envelopes on environment parameters: temperature, solar radiation, airflow, and thereby thermal comfort.

RESEARCH METHODOLOGY

Thermal comfort, as a subjective response or state of mind, is primarily influence by the body's heat exchange with the environment climate parameters: temperature, humidity, air speed (Olesen & Brager, 2004), and corresponds to a temperature range of 20-30ºC DBT and 30-60% relative humidity in still air. (Govt. of India, Energy. n.d.). Personal parameters: clothing (0.5-1.0 clo), activity, or metabolic rates (0.8-9.5 met) are considered to be suited to the season, and the occupants skin temperature and sweating rate as indicated in PO Fanger's Comfort Analysis are not covered. Human body cools down in 3 processes: convection, radiation, and perspiration which are enhance by ventilation (United States, DOE, Energy. 2001). This paper analyze thermal comfort from the perspectives of the environmental parameters due to the effects of ventilation modes and air change, shading, and thermal mass, through conduction, convection, and radiation of heat or cold. Compact traditional buildings or its occupants lifestyle produce little or no heat, where as modern buildings produced much heat of their own, and heat loss through appropriate open-spaces can be beneficial. (Krishan, A. 2001). Ventilation to favorable microclimate through open spaces and retaining 'heat' or 'cold' with high thermal mass envelopes are expected to be conducive to thermal comfort. Besides site survey in Dec, 2013, analysis and simulations were conducted with Solar Designer ver. 6 and Ecotect (2011) on effects of ventilation modes, air change rates, shading, and envelopes thermal mass or glazing, and insulation for a year in House 2, as-built, light thermal mass, and 3 prototype rooms. The paper highlights simulation results in 1) hourly indoor temperature fluctuations and DI (discomfort index), 2) annual heating and cooling load in normal and flex vent systems.

THE ARCHITECTURE: PASSIVE DESIGN TECHNIQUES



a) Optimized L-shaped plan form with north-east *haveli*[1]

b) View of House 2 from north-east

Figure 1 (a) Building plan form with re-interpreted *haveli*[1] for heat sink, shade, and airflow, (b) Build envelope with wood and limestone cladding and landscape trees. Images: Courtesy of Morphogenesis (architects).

A 'place' vernacular architecture and passive design techniques are the manifestation of the local climate, socio-praxis, function, resources and its re-interpretation is expected to afford relative thermal comfort with low-energy. Given the composite climatic pre-requisites and complex programme functions, House-2, in response, was conceptualized as a porous object, through a network of water bodies and re-interpreted L-shaped *haveli*[1] plan that serves as heat sink, shade, airflow or air changes, and envelope with high thermal mass and high emissivity, and visual comforts, as shown in **Figure 1 & 2**.

Site Landscape

House 2's site has a zoning constraint, width to depth ratio of about 1:3 with the shorter side oriented to north entry, and the need to provide for a built-up area of 1508m² on a limited site area of 1003m². Given the pre-conditions that inhibit generation of ideal plan form and geometry or surrounding dusty environment, the site was conceptualized to be a veritable oasis with its own microclimate afforded by radical re-interpretation of *haveli*[1] landscape. The forecourt landscape with grass, tropical plants serve as bio-purifiers and evapotranspiration, while terrace lap-pools and lotus pond affords evaporative cooling, and perimeter trees provides shading, as shown in **Figure 1 & 2**.

Building Plan Form and Geometry

The solar altitude and azimuth, determines the position of the sun. And House 2's orientation, plan form and geometry with respect to sun, compactness or openness envelopes porosity and thermal mass are expected to favorably regulate convection,

1. Enclosed courtyard in private mansions in India and Pakistan.
2. Perforated stone or lattice screens in Indo-Islamic architecture.
3. Mughal emperor's Hall of Private Audience with important guests to deal with important state affairs.
4. Step well to cope with seasonal fluctuations in water availability and evaporative cooling.

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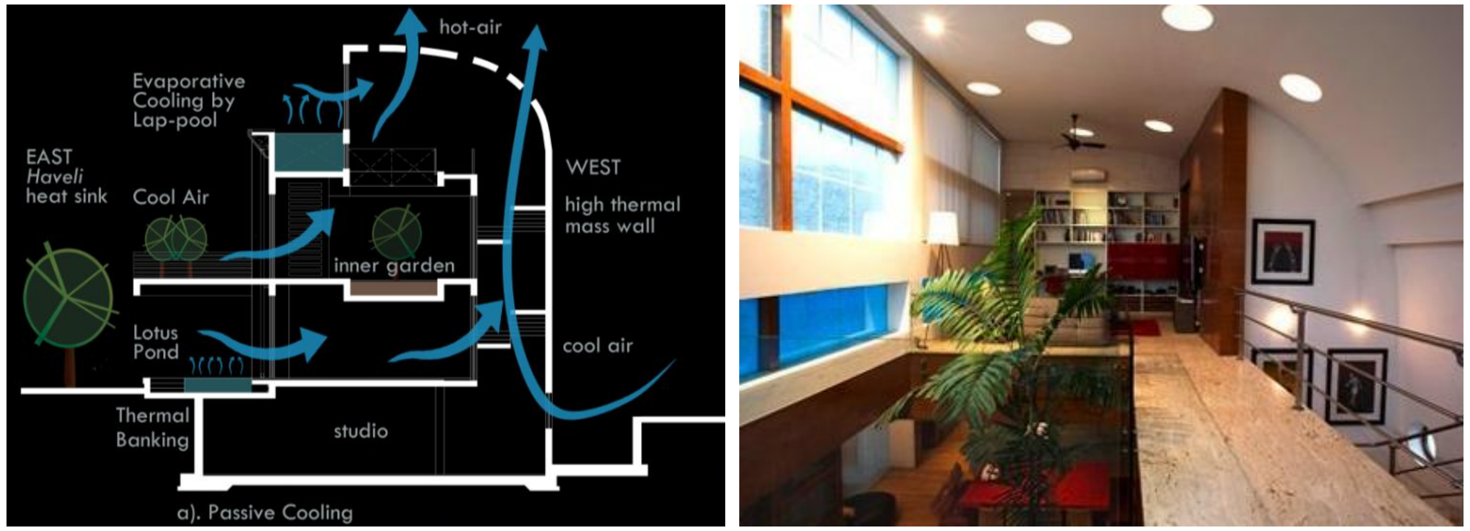
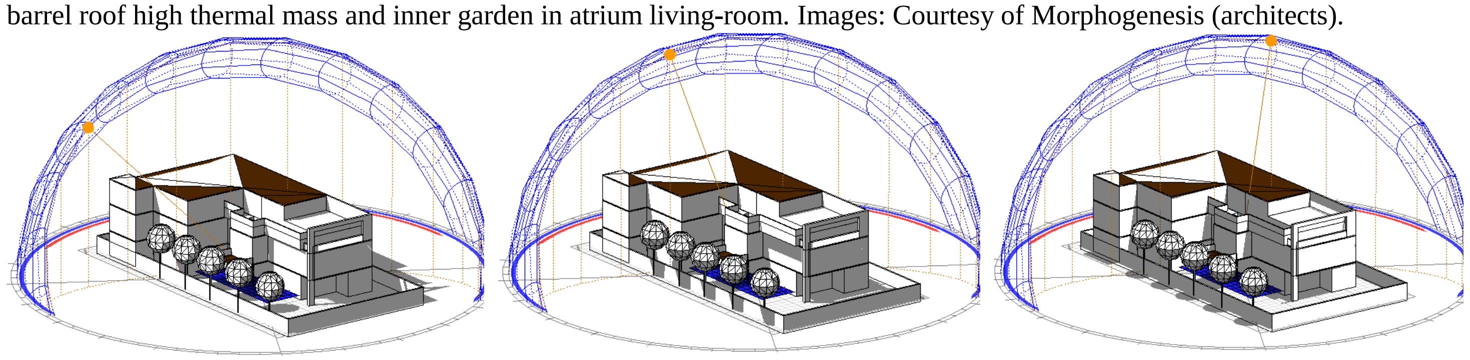
radiation, and conduction of heat or cold. Given the composite climate extremities, House 2 has a solar glass facing the N-east *haveli*[1] heat sink and lap-pool, operable for night ventilation and heat egress, while high thermal mass envelopes with wood and limestone cladding in the South and West controls heat ingress, as shown in **Figure 1 & 2**. These passive design techniques and perimeter trees minimize low altitude east and west solar radiations. Heat conduction is further attenuated with buffer stairs, services, and lap-pool, as shown in **Figure 1 & 2**. The barrel roof and walls high thermal capacity is expected to provide longer time lag, and high emissivity external surfaces are expected to enhance heat loss to sky at night. An outdoor terrace pool deck and *haveli*[1] lawns, as shown in **Figure 2,** save energy by reducing indoor occupancy hours. The diurnal solar geometry's shading pattern was analyzed with Ecotect (2011) for summer, on June 22nd from 8:00 a.m. to 18:00 p.m, as shown in **Figure 3**, winter, spring, and autumn solstices. The analysis shows that the plan form and geometry, landscaped trees, and projected eaves shaded the east glass surfaces adequately, except for a brief interval between 9:00 to 11:00 a.m, as shown in **Figure 3**.



a) East-west section of House 2, in Delhi a) Atrium living-room, test-room in House 2, Delhi

Figure 2 (a) Section showing multiple passive cooling techniques, (b) Glass wall adjacent to north-east lap-pool and *haveli*[1], barrel roof high thermal mass and inner garden in atrium living-room. Images: Courtesy of Morphogenesis (architects).

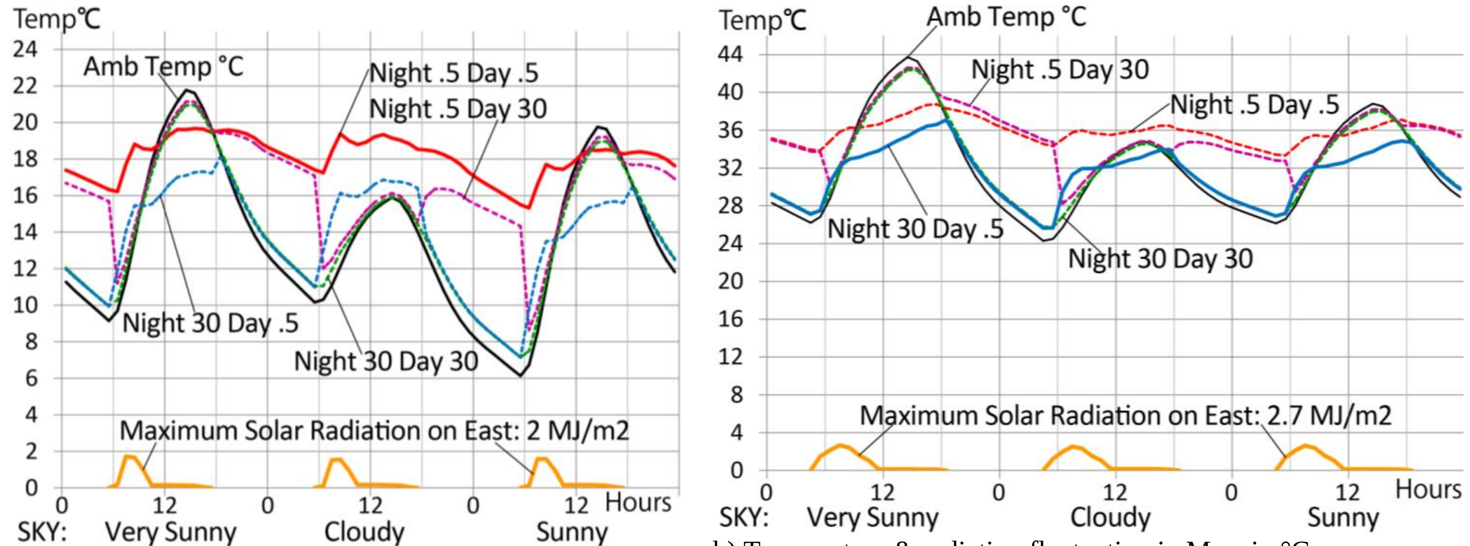


9:00 a.m. 11:00 a.m. 13:00 p.m.

Figure 3 Shading analyses for House 2 with Ecotect (2011) on 22nd June with East façade mostly shaded through the day.

RESULTS AND OUTCOME: COMPUTER SIMULATIONS ANALYSIS

Thermal performance of the building was analyze using Solar Designer Ver. 6 (http://qcd.co.jp/). In Delhi, with high temperature swings, ventilation, and air changes allows the more comfortable part of the day's microclimate to prevail and be retained in the thermal mass, through night-ventilation in summer, and day-ventilation or air-tightness in winter. The simulated living-room atrium, in House 2 (as-built) is considered to be 17m x 12m x 7m high, with high thermal mass in the south and west, high performance glass in the north-east, and adequate insulation for the envelopes wood and limestone panels, as shown in **Figure 1 & 2**. Deep eaves, horizontal and vertical, are considered as per shading analysis, as shown in **Figure 3**. As internal heat sources, a constant 0.84MJ/h for refrigerator, 1.8MJ/h for laundry and dishwashers 6 hours/day, and 3.35MJ/h for 6 family members and 2/3 domestic help were set for 9hrs a day from morning to evening hours. A curtain would be closed as night insulation in the openings. Extensive parametric simulations for various ventilations modes and air change rates for winter (January) and summer (May) in House 2 (as-built), on representative days: very sunny, cloudy, and sunny, shows the best ventilation modes: night-ventilation (30ACH, night, 0.5ACH, day) in summer, and air-tightness (0.5 ACH, night and day) in winter, as shown in **Figure 4**. Monthly best ventilation modes and ACH for a year were selected and temperature fluctuation in the test room highlighted for each month, as shown in **Figure 5**, in order to cover the extremities of Delhi's cold, hot-dry and hot-humid composite climate. The maximum solar radiation on the east facade was about 2 MJ/m^2 in January and 2.7 MJ/m^2 in May, and the glass serves as the media for heat loss to the shaded northeast *haveli*[1] as shown in **Figure 2 & 3**.



a) Temperature & radiation fluctuation in January, in °C b) Temperature & radiation fluctuation in May, in °C

Figure 4 (a) Simulated effects for House 2, as-built, in January, under various ventilation modes, air changes, (b) Simulated effects in House 2, as-built, in May for various ventilation modes, and air changes.

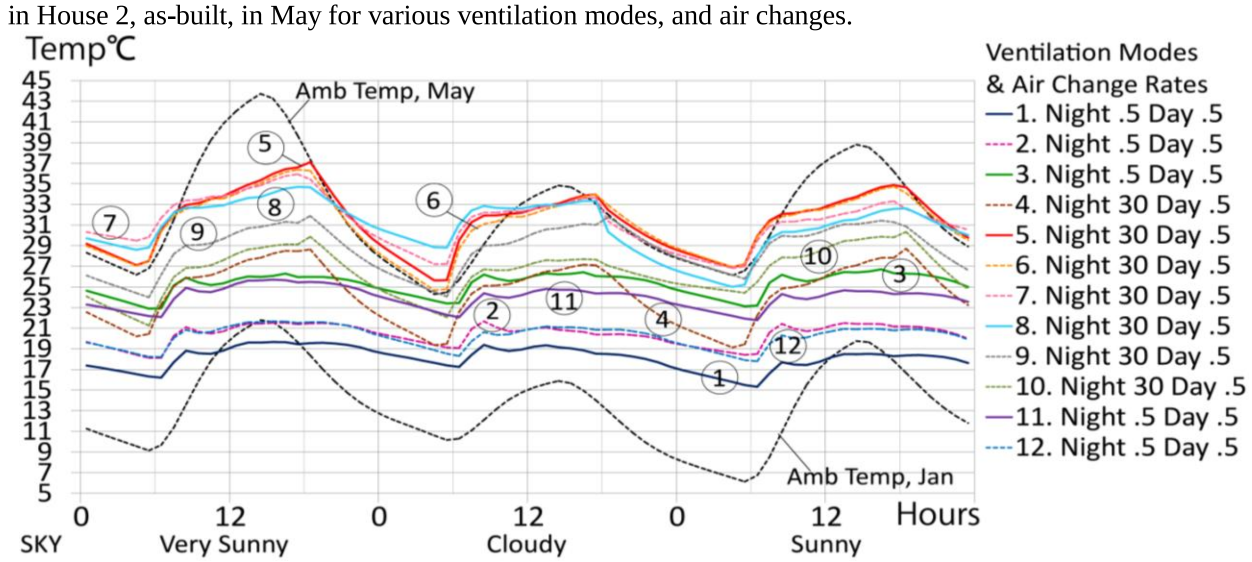
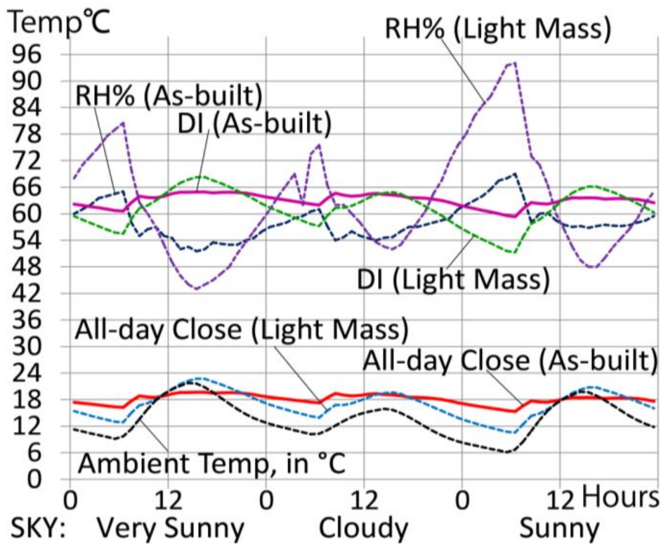
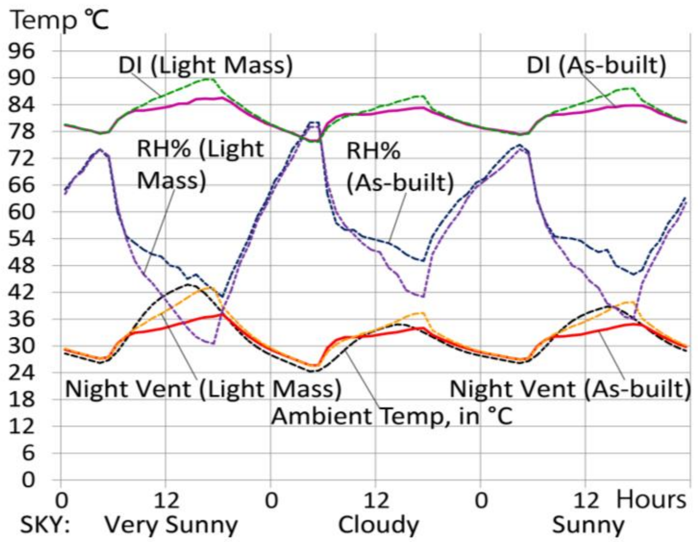


Figure 5 Simulated, monthly best, indoor temperature (°C) fluctuation from January to December, in atrium living room (as-built), due to the effects of ventilation modes, air changes, shading, and thermal mass.

The monthly average indoor temperatures are: January, 18.11 ºC; February, 20.4ºC; March, 25.26ºC; April, 24.44ºC; May, 31.4ºC; June, 31.1ºC; July, 31.3ºC; August, 30.8ºC; September, 28.7ºC; October, 26.47ºC; November, 23.97ºC; December, 20.22ºC, as shown in **Figure 5 & 6**. The maximum indoor temperatures for cooling seasons were: May, 37.1ºC; June, 36.36ºC; July, 35.9ºC; August, 34.7ºC; Sept, 31.8ºC; October, 30.33ºC. Thermal performance of House 2, "as-built" and "light thermal mass", was analyzed from the perspectives of DI (discomfort index) and energy performance, and two extremities for January and May are highlighted. Discomfort Index, DI=0.81Td+0.01H(0.99Td-14.3)+46.3, where *Td*=Indoor Temperature(ºC), *H*=Relative Humidity (%), developed by the American Weather Bureau (US) in 1957, was used to calculate DI after finding the absolute humidity in g/kg of dry air, and relative humidity(%) on psychrometric chart. House 2, as-built, is much more stable and lower than hypothetical House 2 with light thermal mass though Discomfort Index was above 75% (uncomfortable) in May and parts of summer, as shown in **Figure 6(b)**. Annual heating and cooling load for Normal vent without ventilations in House 2, as-built, was about 86% higher than Flex Vent system, 18°C< AT <30°C, with 30ACH when AT (Ambient temperature) is 18-30°C, and 0.5ACH at other times, as shown in **Figure 7(a)**. In hypothetical "light thermal mass" envelopes: 115 thick brick walls with no claddings and single glazing on east facade, energy consumption in Normal case increase from Flex Vent system by about 47%, as shown in **Figure 7(a)**. Percentage change in heating and cooling load between House 2 "as-built" and "light thermal mass" was about 87% in normal conditions without ventilations, and 137% in Flex Vent system. Attenuation of indoor temperature swings reduces energy consumption, as shown in **Figure 7(a)**. Further simulation and analysis was done for 3 prototype rooms: **A, B, C** each measuring 7mX4m with 1mX2.4m door each, to check ventilation effects on glazing area, thermal mass, and insulation. Room-**A** has a 6mX3m glazing with a 2m eave on South, Room-**B** & **C** have small glazing 2mX0.5m. Only Room-**C** was insulated with 10cm thick glass wool. Room-**C** with night-vent (30ACH at night, 0.5ACH in day-time) in summer, and all-day close (0.5ACH, day and night) in winter performed best and holds potential for reduce heating and cooling load, as shown in **Figure 7(b)**. Besides solar radiation and convection, conduction of ambient heat through glass or low thermal capacity walls resulted in high summer temperature in Room-**A & B**, despite providing adequate sunshades.



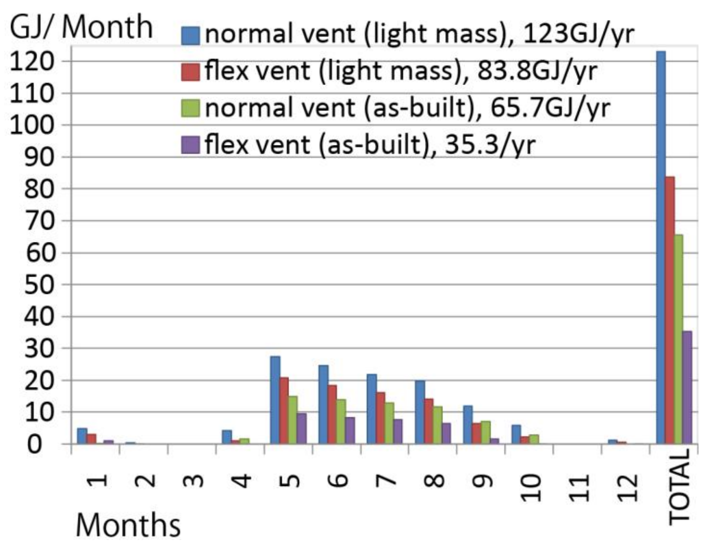
a) Fluctuation of Temp, RH, and DI (Discomfort Index) in January



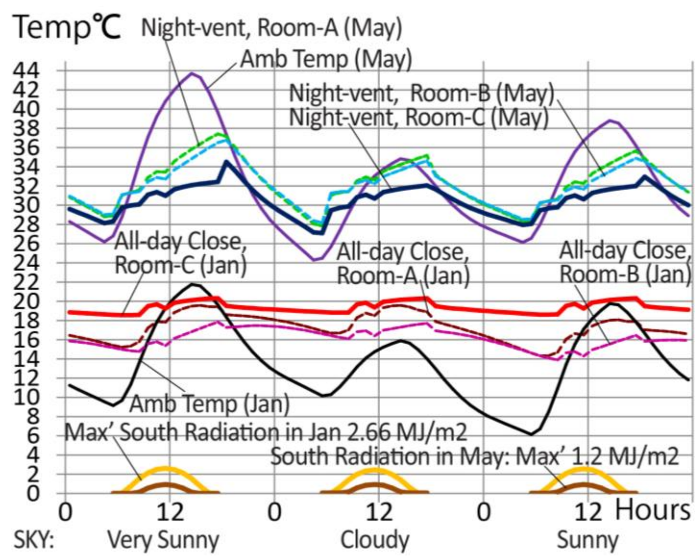
b) Fluctuation of Temp, RH, and DI in May

Figure 6 (a) Thermal comfort parameters: temperature (°C), RH(%),DI in House 2 living-room, As-built, and Light thermal mass, in January, (b) Thermal comfort parameters in May for House 2 As-built and Light thermal mass envelopes.

Energy Performance Analysis



a) Monthly heating & cooling load in House 2, living-room

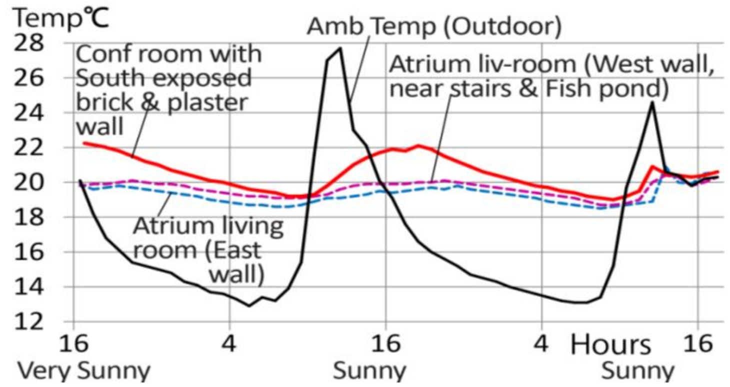


b) Temperature fluctuation for hypothetical cases, A, B & C

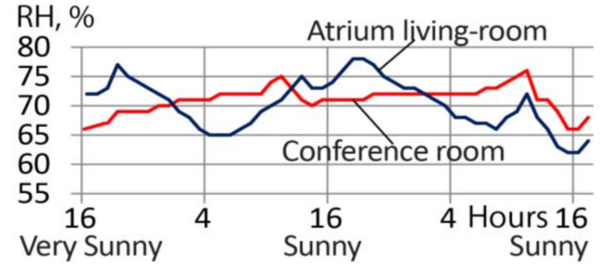
Figure 7 (a) Simulated heating & cooling load in House 2, as-built and light thermal mass, for 9 hours occupancy/day (b) Simulated effects of night-vent (30ACH) in summer, All-day close (0.5ACH) in winter for hypothetical cases: A, B, C.

SITE MEASUREMENTS AND ANALYSIS

The field survey of House-2 was done in the atrium living room and south conference on 16-18th December 2013. The conference room, due to its south and west exposure, thermal mass, and small openings has >20ºC, and stable >70% average humidity, living room has low <20ºC, and less stable <70% average humidity, as shown in **Figure 8**. In both cases, the walls high thermal capacity attenuates indoor temperature rise, and peaks at 16:00 hours though the external temperature peaks at 12:00 hrs, and retained 'heat' to maintain a satisfactory indoor temperature, when the external temperature ranges from 13-27ºC.



a) Concurrent trends of Temperature (°C) in House 2



b) Humidity (RH) was stable, average >70% in south conference room and less stable average <70% in atrium living room on 16-18th of Dec' 2013, due to adjacent heat *haveli*[1] heat sinks, glass, and lap-pool, and water bodies.

Figure 8 (a) Stabilization of temperature swings to approx 18-22ºC in all rooms, (b) Fluctuation of Relative Humidity in %

INFERENCES AND CONCLUSIONS

The paper, essentially, highlights passive techniques conducive to affordance of thermal comfort with low-energy, from the perspectives of environment parameters: temperature, humidity, and air changes. Personal parameters: clothing, activity, or metabolic rates, or skin temperature and sweating rates are not discussed in this report. Passive features regulate climatic phenomena of convection, radiation, conduction of 'heat' or 'cold' through different ventilation modes, air-changes, shading, and envelope materials. In summer, from May to October, thermal comfort was not afforded for fully, without active cooling. However, simulation studies shows that passive strategies and responsive lifestyle could attenuate heat ingress or enhance heat egress through night ventilation in summer, while allowing warmer natural microclimate to prevail and be retain in thermal mass through day ventilation or air-tightness greenhouse effect in winter. While 100% "thermal comfort" may not be possible through passive cooling it is possible to reduce peak energy load, considerably. The historical quintessence of *haveli*[1] or the high thermal mass walls, and evaporative cooling prevalent to Delhi's vernacular architecture have been radically re-interpreted while retaining a progressive architecture milieu. The envelopes thermal mass, and efficient air-tightness resulted in better insulation from the less favorable climatic conditions of 'cold' or 'heat' from outside during summer or retaining heat generated by interior equipments, people, greenhouse effect, etc in winter. The building allows for regulation of solar radiation by shading, convection of 'heat' or 'cold' through optimized forms or operable openings with various ventilation modes and air-changes, and storage of the same with high thermal mass envelopes. While high thermal mass help in attenuating heat gain in summer, it could also result in low stable temperatures in winter. Hypothetical analysis shows insulation was effective in summer and winter. Last, but not the least, heat loss or heat gain through conduction from atmospheric heat in summer can further be regulated more efficiently by optimizing the glass and concrete ratio on the perimeter surfaces at appropriate locations towards affordance of a thermally comfortable milieu that remembers the past, embrace the present challenges, and envisaged the future.

ACKNOWLEDGEMENTS

These research activities or the paper is made possible due to the encouragements, continue support, and guidance of teachers, architects, house owners, family, friends, and in essence, all who directly or indirectly contributed to its progress and refinement. The authors are grateful to all concern, especially Dr. Arvind Krishan, Morphogenesis and the Rastogi family for their hospitality, sustained interests and commitments to architecture in general and sustainable passive designs in particular.

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Out of Phase: Building Scale Analysis for Zero Energy Master Planning

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ABSTRACT

This paper presents a process for developing comparative quantitative energy and comfort analysis for a site and program before master planning begins. Loisos + Ubbelohde developed this process serving as technical experts for a public high school with zero-net-energy goals. Studying the programmatic needs of the classroom relative to the comfort needs of a classroom, energy models were used to explore the potential for passively delivering comfort with low energy approaches in this climate. Daylighting studies generated input for lighting loads and schedules for the energy use and comfort models. This information generated by the technical assistance team was then used by the Architect to efficiently begin the master plan design grounded in scientific principles, rather than less precise rule-of-thumb measures and general guidelines often employed at this early stage of master planning.

INTRODUCTION

Early design decisions often have the largest impact on a building's energy use. These decisions, as early as the master planning stages of a project, are often made without the benefit of quantitative analysis. Later in the design process, when we typically have energy and possibly thermal comfort analyses available, changing these large-scale decisions can be difficult. This paper presents a process for developing useful quantitative energy analysis for a site and program before master planning begins. The information gained from these analyses was provided to the architectural design team at the beginning of the master planning phase of the project. The report allowed the design to commence thoughtfully with regard to energy and was essential in moving towards a zero net energy goal on a limited budget.

INTENT AND OBJECTIVES

This work was funded by Pacific Gas & Electric (PG&E), the local utility company, as part of their Zero Net Energy Pilot Program that provides technical design assistance for local projects trying to achieve Zero Net Energy performance. In addition to assisting in the creation of a number of zero net energy projects, the goal of the program was to transfer knowledge from technical assistance teams to other design team members on the projects.

Through this program, our expertise was provided to Oakland Unified School District (OUSD), a client committed to Zero Net Energy and yet without additional funds to support this level of expertise. OUSD wished to leverage the assistance offered by the program to also develop a process by which they could look at various sites throughout the school district, which contains 87 schools and over 36,000 students. The project for which OUSD received technical assistance was a master planning project for the renovation and rebuilding of Fremont High School, a campus with the potential to support up to 1,700 students.

Figure 1 *Final Master Plan for Fremont High School in Oakland, CA, designed by Cody Anderson Wasney Architects.*

Our team was assigned to this client and project before the architects themselves were chosen. This offered us an atypical opportunity to develop generative, energy-related information for the project before the architects started their work. By developing energy and thermal comfort analyses that had direct design implications before the architects began their design, we provided a rooted understanding of the energy potentials of this specific site paired with the particular program. Our goal was to inform the architect's understanding of the energy considerations inherently embedded in the broad decisisons that define projects early on.

CLIMATE + PROGRAMMATIC ANALYSIS

We began with an inventory and assessment of the existing campus physical conditions and energy use, followed by a study of on-site renewable potential. This was followed with a more unique investigation of the passive potential. The goal of economical zero-net-energy performance requires maximum hours of comfort delivered passively through building envelope design and control without mechanical conditioning. Our strategy was to speculatively examine potential passive retrofit and new design alternatives for the classroom and library spaces that make the bulk of campus. Simulations of various envelope configurations quantified the impact of natural ventilation, thermal mass, super-insulation, glazing specification, and daylighting controls on both the annual energy use and the hour-by-hour thermal comfort of occupants.

The process is based on the premise that the overall site organization is best informed by a detailed understanding of component performance. By finding a way to do detailed modeling before design begins, designers can use analysis specific to their climate and site in order to inform larger scale design decisions.

Climate Summary + Inventory of Existing Conditions

The climate summary and inventory of existing conditions of the buildings on the site was our first step. Master planners are tasked with determining which exising structures to maintain and which to demolish. In our inventory each existing building on campus was rated for its potential to incorporate energy saving strategies, such as thermal mass, natural ventilation, daylighting, efficient electric lighting and mechanical systems. In addition, a full inventory of all mechanical equipment was taken. The inventory included an evaluation of each existing building for its ability to provide passive comfort if it were upgraded.

Figure 2 *From left to right: Library West façade, South classroom building Southwest façade, view of interior classroom, and typical rooftop air conditioning unit.*

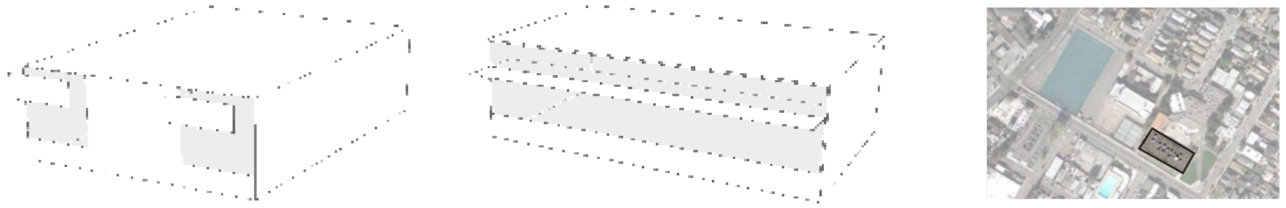

Figure 4 *(a) Typical Existing Classroom, with existing window configurations and existing sunshades, (b) Ideal Classroom, with continuous glazing and sunshade, and (c) aerial photograph of existing Fremont High School, right, with the building from which the Typical Existing Classroom was taken outlined.*

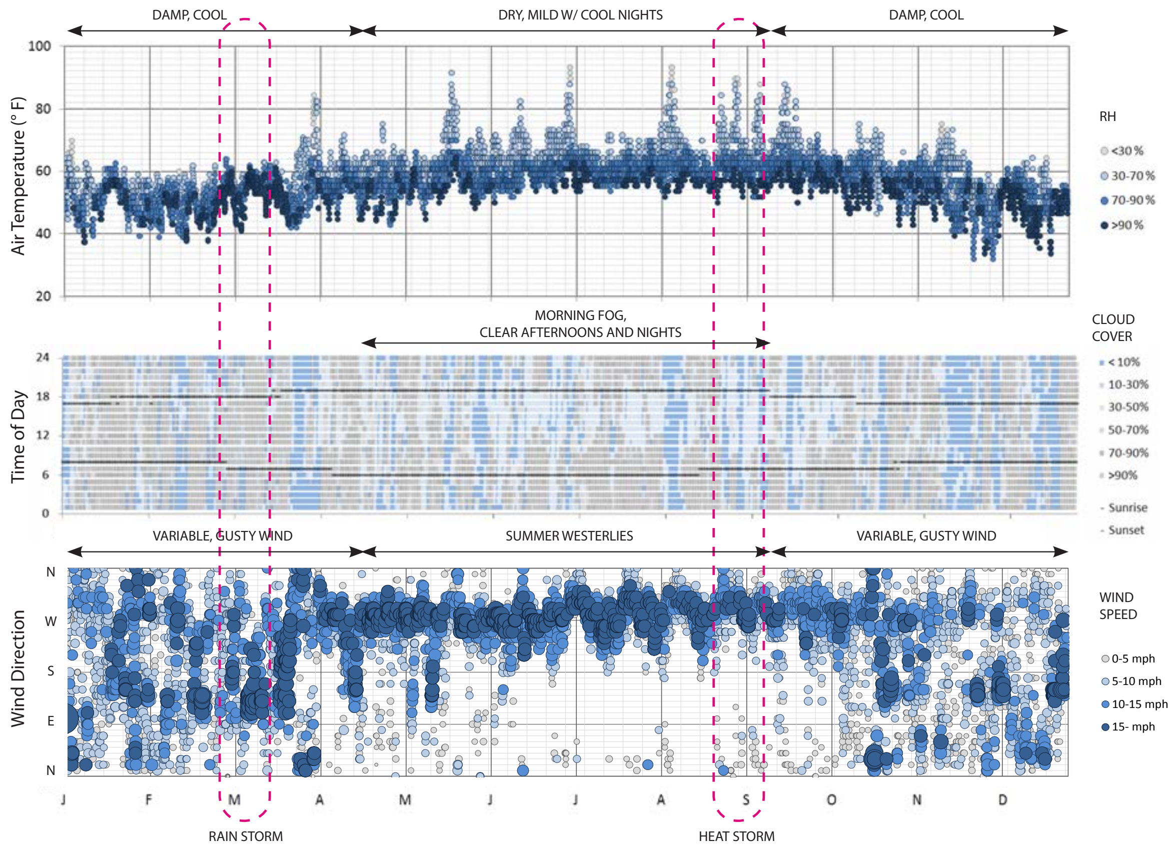

Figure 3 *Hourly Climate Analysis including Air Temperature, Relative Humidity, Cloud Cover, and Wind Speed based on data from the Oakland Airport.*

Ideal and Existing Classrooms

The campus was split into component parts in order to develop more detailed knowledge about how a particular program piece will interact with the climate on site. The classroom, which is repeated many times, was a starting point for investigation. We compared a typical existing classroom with an "ideal" classroom, defined as maximizing passive use of light and air with the same square footage. This allowed us to simultaneously look at a) how close the existing classroom is from a comfort perspective to what we would consider an ideal energy-use scenario, and b) to test various passive strategies for this particular site on two configurations to help the designers consider form and shape of the classroom unit.

In most integrated, sustainable design practices (see, for example, Mendler and Odell, 2000) energy analyses beyond a baseline model do not come into the process until after an initial design has been proposed. Working without a preliminary design and instead using conceptually defined "ideal" design characteristics for a repeated unit on the campus set a high bar for the design team. This strategy is well suited to any program with repeated or dominant elements.

Energy Models

We modeled the Ideal and Typical classrooms using EnergyPlus, a simulation platform that accounts for sub-hourly building envelope heat flows through conduction, convection, and radiation. The model contains envelope geometry, shading devices, and orientation as well as assumptions about ventilation strategy, construction assemblies, and internal gains. Typical meteorological year (TMY) data for Oakland International Airport (located 3 miles away) was used for the analysis.

EXISTING CLASSROOM				IDEAL CLASSROOM			
SOUTH EAST	NORTH EAST	SOUTH WEST	NORTH WEST	SOUTH EAST	NORTH EAST	SOUTH WEST	NORTH WEST
44.92	45.76	43.71	44.64	40.73	42.59	39.83	41.35
64%	**65%**	**62%**	**64%**	**58%**	**61%**	**57%**	**59%**

Figure 5 *Baseline energy models for Existing and Ideal Classrooms in four orientations showing total energy use in kBTU/SF and the percentage of roof area required to be covered by PVs to meet Zero Net Energy.*

Thermal Comfort Models

The most energy is saved if comfort is achieved passively, without active systems. We began by modeling thermal comfort conditions in the classrooms with no conditioning and no passive operations (such as operable windows). Figure 6 shows comfort levels for every hour of the year, with the color red indicating it is too hot (cooling would be required) and blue and purple indicating heating would be needed. No color signifies comfort is achieved passively for that hour. Parametric simulations enabled us to identify suites of passive strategies that minimizes need for mechanical conditioning.

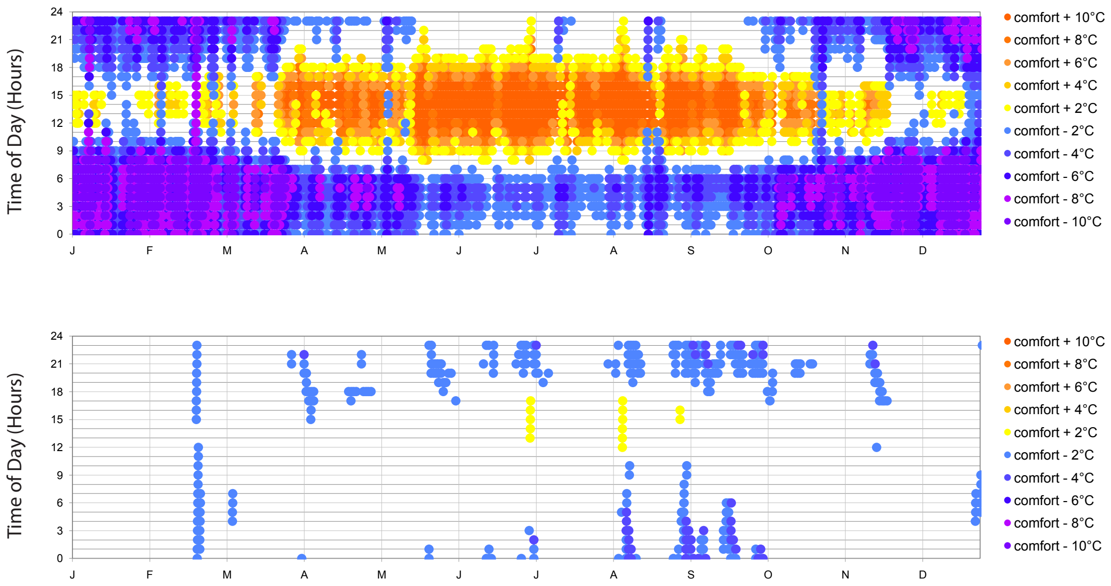

Figure 6 *(a) Annual Hourly Comfort for an unconditioned ideal classroom without insulation or passive strategies, and (b) Annual Hourly Comfort for an unconditioned ideal classroom with insulation, thermal mass, daylighting controls, and natural ventilation used when needed.*

Daylight Models

In order to determine the potential for reducing use of electric lighting, we modeled the classroom with Radiance, a research grade simulation tool developed by Lawrence Berkeley Laboratory. We studied the typical existing classroom, the typical existing classroom with added skylights, the ideal classroom, and the ideal classroom with added skylights. We also used Radiance to provide hourly electric lighting use for input into the energy models.

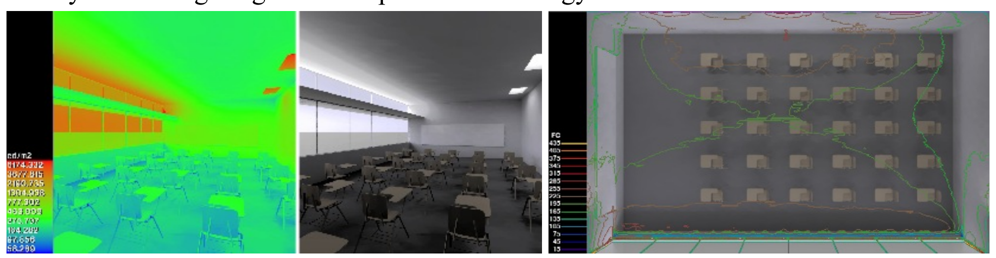

Figure 7 *Ideal classroom daylighting simulation for a SouthWest facing classroom at Noon on March 21st, under clear skies. (a) Falsecolor luminance map of surface brightness, (b) perspective view, and (c) illuminance levels in footcandles, measured at desk height, 30" above the floor.*

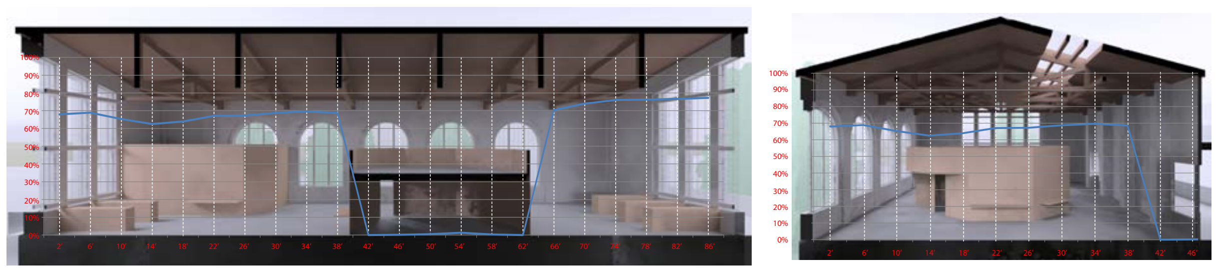

Figure 8 *Daylight Autonomy of existing library building assuming daylighting controls and motorized shades.*

Comparing Conditioned Optimized Models

The daylighting modeling and the optimized comfort models were used to develop an optimized design that was then modeled in EnergyPlus. Energy use in the optimized retrofit design was reduced by half, from approximately 44kBTU/SF to approximately 22 kBTU/SF in the typical classroom. In the ideal classroom, energy use was lowered to 16kBTU/SF, requiring only 23% of roof area to be covered in PV to meet Zero Net Energy goals.

EXISTING CLASSROOM				IDEAL CLASSROOM			
SOUTH EAST	NORTH EAST	SOUTH WEST	NORTH WEST	SOUTH EAST	NORTH EAST	SOUTH WEST	NORTH WEST
21.75	22.53	21.46	22.11	16.13	16.61	16.17	16.48
31%	**32%**	**31%**	**32%**	**23%**	**24%**	**23%**	**23%**

Figure 9 *Optimized energy models for Existing and Ideal Classrooms in four orientations showing total energy use in kBTU/SF and the percentage of roof area required to be covered by PVs to meet Zero Net Energy.*

CONCLUSION

Providing the design team with detailed analysis of the energy potential of the site and program allowed the team to move in a direction conducive to passive strategies immediately in their design process. Access to light and air became primary informants to program locations and orientations on the site at the onset. Typical and Ideal classroom studies allowed the team to understand the passive needs of the project so they could immediately begin to negotiate these with other needs of the project including mitigating outdoor air quality and acoustics. The early studies enabled the architects to quickly and effectively produce detailed master plans proposals that convinced their clients that a Zero Net Energy campus is possible.

Figure 10 *Architectural scale strategies were brainstormed to resolve master planning issues in eco-charrettes.*

ACKNOWLEDGMENTS

This study could not have been completed without the support and cooperation of the Pacific Gas & Electric Zero Net Energy Pilot Program, Oakland Unified School District, Cody Anderson Wasney Architects, Integral Group, SJ Engineers, and William McDonough + Partners.

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Session 3A : Lessons from vernacular architecture

PLEA2014: Day 1, Tuesday, December 16
16:05 - 17:45, Auditorium - Knowledge Consortium of Gujarat

The 'Teatinas' of Lima: Energy Analysis and Possibilities of Contemporary Use

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ABSTRACT

"Teatinas", roof openings for zenithal ventilation and daylighting, were systematically used in buildings in the city of Lima and in most of the Peruvian coast from the mid-18th century to the end of the 19th century. The purpose of the study was to evaluate the thermal and lighting performance of the rooms where the "teatinas" were used and to assess an eventual use of similar resources in contemporary architecture. After defining the climate of the city, the buildings where they were installed and the "teatinas" themselves, the thermal and lighting conditions resulting from their use were calculated based on comparative measurements and simulations: air temperature and relative humidity, ventilation, lighting levels and glare. The results showed that the presence of a "teatina" in a room provides comfortable hygrothermal conditions, good air intake and circulation inside a room. As compared to conventional windows, the "teatina" allows for a more even distribution of daylight inside the space and more possibilities of avoiding glare. Finally, it is concluded that "teatinas", consistent with the climate and daylighting conditions of the city of Lima, did fulfill the comfort requirements of homeowners of that period of time and are a valid reference and concrete alternative in the current search for comfortable spaces in energy-efficient buildings.

INTRODUCTION

The addition of *teatinas* on the roofs of Lima buildings became widespread after the 1746 earthquake. Despite the temperate climate of the Peruvian coast, its recurrent use was due to the need of providing natural ventilation and light to spaces which, due to the density and homogeneity of the urban grid, had little or no access to outside breezes and daylight.

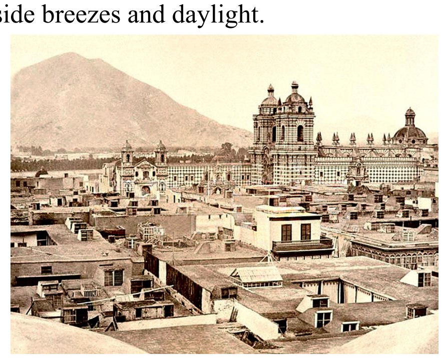

Photo 1: View of the Church of San Francisco from the Cathedral of Lima (circa 1860) with dozens of "teatinas" on the roofs. http://www.corbisimages.com/stock-photo/rights-managed/IH074568/church-of-san-francisco-lima?popup=1.

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Photo 2: "Teatina" on a building located at the intersection between Camaná and Callao Streets, showing typical proportions and characteristics.

Teatinas were systematically incorporated in buildings until the end of the 19th century. Afterwards, Neoclassical architecture, and later modern architecture, excluded them completely. The strategy of catching wind and capturing natural light through the roof has not been maintained or resumed in the Peruvian coast. This study examines the objective thermal and lighting conditions achieved by the presence of a *teatina* in a room, and its ability to provide thermal and lighting comfort in the spaces where it is present. This study has been more fully developed and submitted in a doctoral dissertation [1].

METHODOLOGY

Given the inexistence of similar research studies in Peru, it was necessary to address previously certain aspects in order to be able to choose appropriate indicators for the energy assessment to be developed within this study.

In addition to determining the definition, the variables and the evaluation of thermal and lighting comfort, it was necessary to identify the energy assessment tools and the most common environmental control strategies in architecture. The geographic, climatic and lighting characteristics of the city of Lima were identified and a prior study was made to relate the *teatina* to its historical context. Ten buildings containing a total of ninety-seven *teatinas* were surveyed and measured in order to identify typical construction characteristics and components –as related to the particular features of the urban grid– of the buildings and rooms where they were found.

Afterwards, a 'model room' containing a 'model *teatina*' was defined. Jointly, both have typical characteristics insofar as orientation, layout, dimensions, form and finishes. These models were used in the simulations and some assessments were performed in settings with similar characteristics, since they had to be made on-site. The 'model' room is a quadrangular space, 5 meters long by 5 meters wide, with a height of 4.20 meters. For the lighting assessment, a 'contemporary' height of 3.00 meters was considered as an additional variant. The dimensions of the 'model' *teatina* were defined based on the sampling average, as well as the typical orientation of the opening (SSW).

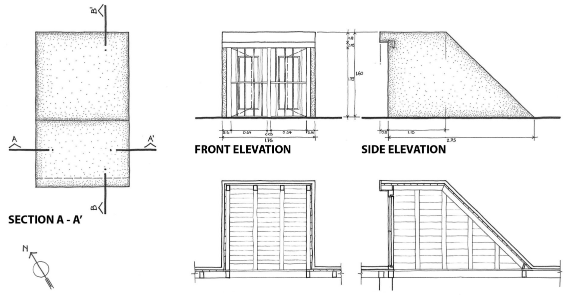


Figure 1. Dimensions and characteristics of the model "teatina".

The purpose of the energy assessment was to identify the thermal and lighting behavior of the 'room/*teatina*' combination as compared to its objective capacities of providing comfort to its occupants. Specifically, the following aspects were evaluated:

Table 1. Energy Assessment Aspects

Aspects to be Evaluated	Method	Resource or Instrument
1. Thermal Assessment		
Solar Radiation	Computer Simulation	Nomogram/AutoCAD
Ventilation	On Site	Thermo-Hygrometer/Anemometer/Smoke
2. Lighting Assessment		
Lighting Level	Models	Lux Meter/ Model
Glare	Calculation	Glare Index

RESULTS

Thermal Assessment

In order to calculate the effect of **solar radiation** on the *teatina*, both that which passes directly through the opening and that which falls on its opaque structure were taken into account. In the first case, the equidistant solar projection was used to identify the months and hours when direct solar radiation entered through the opening, and a nomogram was superimposed on the former in order to obtain the incidental energy. Using AutoCAD, a graphic image of the entrance of direct solar radiation into the room was obtained.

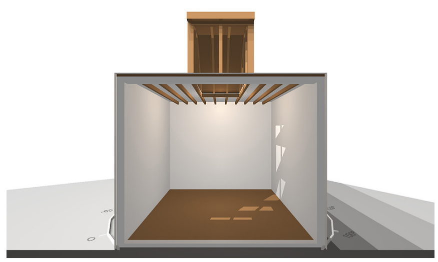


Figure 2: AutoCAD simulated rendering on the month when most direct solar radiation enters through the "teatina": December

The result was that the cumulative daily average of solar energy entering the room in the months of January and February ranges from 2.5 to 3.5 kWh, being higher at around 4:00 pm (approximately 0.9 kWh), when the eave presents the least obstruction and the sunrays are most perpendicular with respect to the opening.

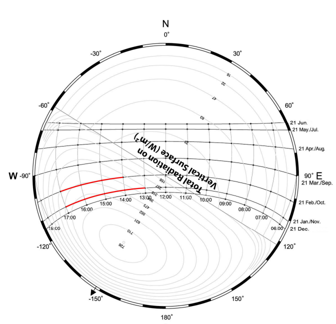


Figure 3: Nomogram superimposed on solar projection. Based on times of day, the amount of direct and diffuse solar energy through the "teatina" opening facing SSW is inferred.

To predict the energy passing through the opaque surfaces of the *teatina*, thermal transmittance was calculated taking into account the ‘sun-air’ temperature (tsa). Given that the air temperature entering the *teatina* is equal to the external temperature, the following formula (Evans, 1980) was applied:

$$Q = U \bullet A \bullet \alpha \bullet R \bullet r_o, \qquad [2]$$

According to this calculation, the approximate amount of energy (Q) passing through the opaque surfaces of the *teatina* is close to 0.17 kWh. This value proved to be rather low, since the transmittance of the element, consisting of a packed mud layer about 10 cm thick, which also shares the characteristics of the rest of the covering, is equally low.

From the values obtained, it can be stated that both the direct and diffuse solar radiation entering through the *teatina* opening and the heat passing through the opaque material are not enough to significantly raise the interior temperature of the room. The relatively low energy values and the ventilation provided by the component itself ensure continuous outflow of excess heat.

To evaluate the **ventilation** in a room having a *teatina*, the energy conditions of the air and the air movement within the space were assessed.

On-site testing in the *Casa de la Riva* during 72 consecutive hours comprised temperature and relative humidity measurements in a single room under two different conditions: with the *teatina* open and with the *teatina* closed. The results are depicted in a psychrometric chart showing summer comfort zone limits and comfort zone corrected with ventilation, as per Coch and Serra (1994) [3].

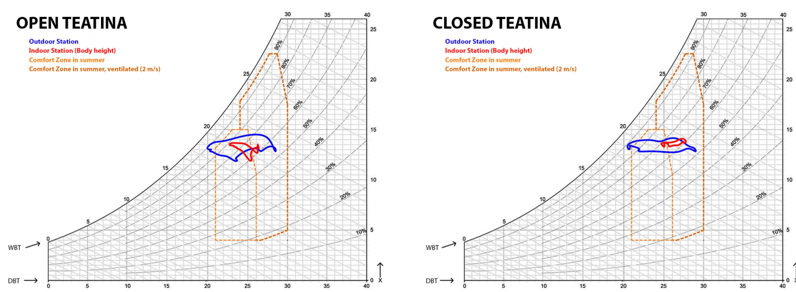


Figure 4. Psychrometric chart showing temperature and relative humidity data, considering vertical opening of the open (left) and closed “teatina” (right). Outdoor stations (in blue) and indoor stations (at human occupant level, in red) are represented. Testing was carried out during particularly hot and sunny summer days.

Although on both days the external temperature was close to 29 °C at the warmest moments, it was observed that, with the *teatina* closed, indoor temperature reached almost 28 °C, while with the *teatina* open, indoor temperature stayed at around 26° C. These results are due to the presence of an indoor thermal mass that was cooled by the ventilation itself in the preceding hours, and to the ability of constantly expelling the air being heated inside. As to the air movement pattern within a room equipped with a *teatina*, site measurements were made in the Casa de la Riva and the Casona de San Marcos to determine speeds and direction, using in this case an anemometer and a smoke machine.

Photo 3: Smoke tests to detect indoor air movements created by an open "teatina". Casona de San Marcos, Lima.

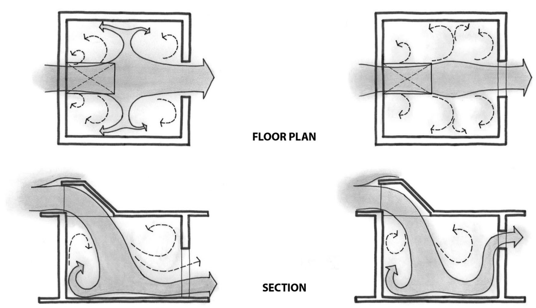


Figure 5: Typical wind movement patterns inside a room with a "teatina" and a door (left) or a window (right) facing the "teatina".

Wind directions are rather particular since, regardless of the location and the size of the exit opening, the incoming air direction is markedly vertical. Once it reaches the floor, it spreads horizontally in all directions, mainly away from the inflow direction. Incoming air mixes with existing air and finally leaves through the opening on the opposite side (Figure 5). Wind speed inside the room, at the lower section of the *teatina*, is between 30% and 60% of outdoor wind speed. Outdoor air descends rapidly once inside the room, though it is warmer than existing indoor air, because of the pressure differences created by the wind itself, since both, outdoor and indoor air, quickly mix due to the existence of continuous convective movements within the space.

The resulting temperatures inside a room equipped with a *teatina*, in addition to wind presence and speed, ensure thermal comfort for occupants under typical hot summertime conditions in the city of Lima.

Lighting Assessment

Illuminance measurements were performed using scale models, considering a work plane at 80 cm from the floor, overcast sky and 'model' room and *teatina* characteristics. Table 2 shows average DF results (%, Daylight Factor) from various situations, followed by iso-DF curves (Figure 6).

Photos 4 and 5. View of the Room A.01 model and detail of the roof and "teatina".

Table 2. Characteristics of Openings and the Room to Measure Lighting Levels

Room Model	Description	DF (%) Average
A.01	*Teatina* / roof covering with joists / 'traditional' roof height (4.20 m)	1.13%
B.01	*Teatina* / smooth covering / 'traditional' roof height	1.61%
B.02	*Teatina* / smooth covering / 'conventional' roof height (3.00 m)	1.94%
C.01	High window / smooth covering / 'traditional' roof height	1.98%
C.02	High window / smooth covering / 'conventional' roof height	2.37%

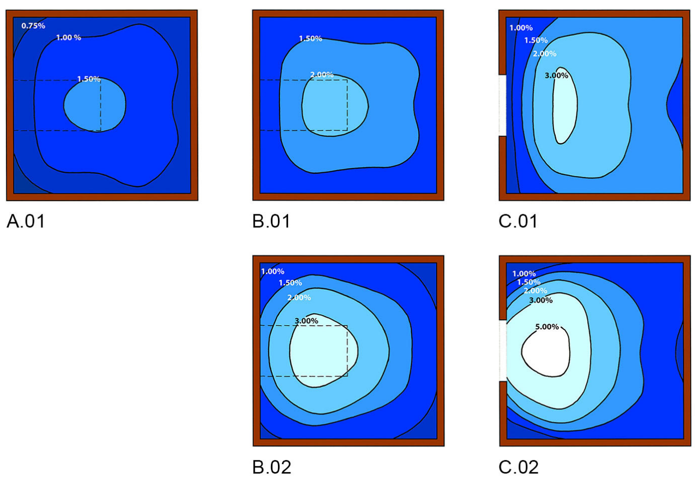


Figure 6. Light distribution at the work plane in the various rooms.

Considering that minimum values suggested for home environments range from 0.5% to 0.6% (Baker & Steemers, 2002) [4], it can be stated that the results obtained under any of these scenarios far exceed those requirements. To the extent that the lighting level values obtained from Europe overcast sky and in the north of the United States of America represent approximately one third of those reached in our tropical latitudes, it can be stated that the illuminance obtained from all of the results are suitable even for tasks requiring greater precision (classrooms, reading areas, etc.).

Light distribution patterns show that in a room with a *teatina*, lighting is distributed more evenly as compared to a room with a conventional high window with the same dimensions. In addition, the greater height of the space is confirmed to provide more homogeneous illuminances, with higher values in the area facing the opening.

To determine the **glare**, the Unified Glare Ratio (UGR) was applied, using the following formula (CIE, 1995, p. 117):

$$UGR = 8 \log [(0{,}25/L_b) \bullet \Sigma (L^2 \bullet \omega/p^2)] \qquad [5]$$

Possible glare was determined by considering the 'model' room with *teatina*, a sight line at a height of 1.20 meters, five different points inside the room and four typical scenarios of sky brightness and lighting level (Figure 7). Projections were made considering both the 'traditional' and the 'conventional' (contemporary) height of the room. The results of the various scenarios are shown in Figures 11, 12, 13 and 14.

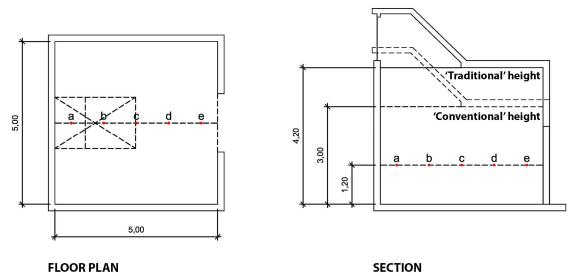
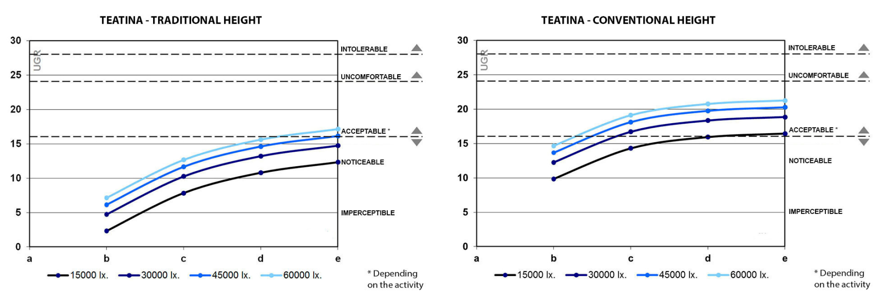
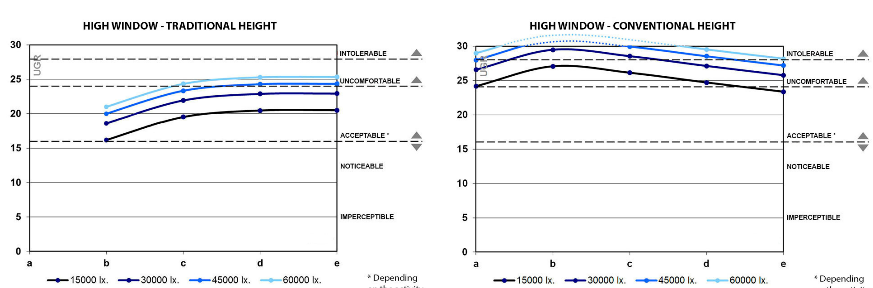


Figure 7. Model Rooms and Measurement Points for Assessing Glare



Figures 8 and 9. Results in a room with a 'traditional' height (4.20 m, B.01) and a conventional height (3.00 m, B.02), with "teatina".



Figures 10 and 11: Results in a room with a 'traditional' height (4.20 m, C.01) and a conventional height (3.00 m, C.02), with high window.

Despite the relativity of the results given that both the height and the sight line direction are usually variable, it is confirmed that the overhead lighting – in this case provided by the *teatina* – performs better in preventing the visual discomfort associated with the glare phenomenon, as compared to conventional lateral natural light.

CONCLUSIONS

Teatinas, consistent with the climatic and light characteristics of the city of Lima, did meet the comfort requirements of the city inhabitants of the time, who incorporated them systematically in buildings for more than one hundred years since the mid-18th century. In addition to good wind uptake and distribution inside the rooms, their lighting performance is better than that of a conventional window, because *teatinas* distribute light more evenly within a space and are more likely to prevent glare.

The thermal and lighting conditions achieved in rooms having *teatinas*, show that these elements continue to represent a valid design alternative to be considered. Based on the identification and comprehension of the phenomena associated with the energy performance of *teatinas*, alternatives and specific details may be proposed in order to improve their efficiency and adapt them to various contemporary applications.

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Influence of Greenery in Cooling the Urban Atmosphere and Surfaces in Compact Old Residential Building Blocks: A Building Morphology Approach

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ABSTRACT

Outdoor thermal environment at great extent determines the possibility and vitality of outdoor social activities and communication. The hot air and heated surfaces in tropical/subtropical areas during summer period would compromise the outdoor thermal environmentt in the city. This study aims to investigate the effect of street trees in cooling the air and surfaces in traditional high-dense residential area in Hong Kong. Sham Shui Po is a traditional residential district in Hong Kong with relatively regular building arrays oriented in different orientations. With simplified morphology, this paper aims to investigate the influence of building morphology and tree configuration on greenery cooling. In the simulation, the testing parameters including sky view factor (SVF) and orientation of street canyon, and the leaf area density (LAD) of the tree crowns. Based on the findings from parametric study, case study adopting the existing building morphology was also conducted to offer further understanding in greenery cooling. This study is expected to offer site-specific greening design suggestions for tropical/subtropical cities with compact building layouts. The simulation result shows that cooling efficiency varies with tree crown density. With the average of the LAD profile being 0.5 or above, substantial cooling in urban atmosphere and surfaces can be achieved in compact residential neighborhoods. And with denser tree crowns of LAD averaged at 1.0 or above, the mean radiant temperature would be reduced to a comfortable level of 33 degree in hot summer.The study also revealed with the high summer solar angle at noon, the cooling outcome under different orientations would be more homogenous with higher SVF; and for lower SVF condition, the cooling effect differs along streets sections and varies with street orientation. For subtropical cities, it is an effective measure to shade the street-crossing areas in high-dense neighborhoods to avoid overheat problem.

INTRODUCTION

As one of the world’s highest-density cities, Hong Kong suffers serious urban heat island (UHI) with a maximum intensity of 4 °C. To mitigate the UHI effect, several measures have been proposed, including greenery. and study by Ng et al. (2012) revealed that greening coverage larger than 33% would reduce the local thermal load, one of the two most important urban climatic evaluation factors, by 1 class in the Urban Climatic Map of Hong Kong. Nevertheless, the greening coverage ratio is much lower than the recommended value in many densely built urban areas. The situation is particularly serious in aging residential districts with compact building layouts and large population density.

Greening design should be applied in residential neighborhoods to provide better living condition (Givoni, 1998). As a planning reference, site-specific greenery design strategies should be established upon clarifying the local thermal condition in the neighborhoods. Thus, the current study investigates the impact of urban tree design on the enhancement ofoutdoor thermal enironment in compact residential neighborhoods. From previous studies, it has been pointed out that sky view factor (SVF) is a key parameter to be considered in morphology-approach thermal study. Study of Mills (1996) demonstrated that minimizing the relative exposure and maximizing the SVF improve thermal performance of building group design in tropical and subtropical areas. Giridharan et al. (2004) studied the UHI intensity and mitigation in Hong Kong, and it was found that 1% reduction on sky view factor (SVF) reduced day-time UHI by 1-4%. Correlation between intra-urban temperature difference and areal means of SVF has been studied by Unger (2009). It was summarized that ground level SVF was recommended for individual point/site investigation, while areal averaged SVF at pedestrian height obtained a better result in predicting the temperature deviation between sites. An inverse proportion was found between the areal averaged SVF and air temperature elevation in urban areas of Hong Kong (Chen et al., 2012), and in high-density city, the influence of SVF as a quantifier was different in various density. Giridharan et al. (2008) analyzed the vegetation effect on UHI mitigation under different SVF settings, but the study only covered relatively small range of low SVF values.

To investigate the vegetation effect in the context of building morphology, urban canyon as the basic morphology unit has been selected as setting in previous studies. Study by Shashua-Bar et al. (2006) revealed that with the tree coverage being 64% and the aspect ratio ranging from 0.2 to 0.6, the cooling effect of the tree achieved 2.3K. Ali-Toudert et al. (2007) studied the effect of configuration and vegetation cooling in urban canyon by simulation, and the results showed that compared to air temperature, radiant environment was more sensitive to canyon geometry. The vegetation created a decrease on PET value of 22K within the tree canopy in canyon with aspect ratio of 2, and the value was even higher as 24K when the aspect ratio was 1. Shashua-Bar et al. (2012) studied the passive cooling efficient of green urban canyon with numerical modeling, and the result showed the greenery cooling effect was highly related to the canopy coverage.

Sham Shui Po in Hong Kong is a traditional high-density residential district. This district is also a climate sensitive waterfront area with summer prevailing wind from the sea. In the study, the building morphology of SSP will be adopted in parametric studies with ENVI-met simulation to investigate the influence of tree crown configuration on the cooling efficiency under the context of different sky view factor and street orientations. Based on the finding from parametric study, the greenery design scheme will be tested with the existing morphology of the district as case study. Data from small scale site survey will be used to validate the microclimate and vegetation model in ENVI-met with Hong Kong's condition.

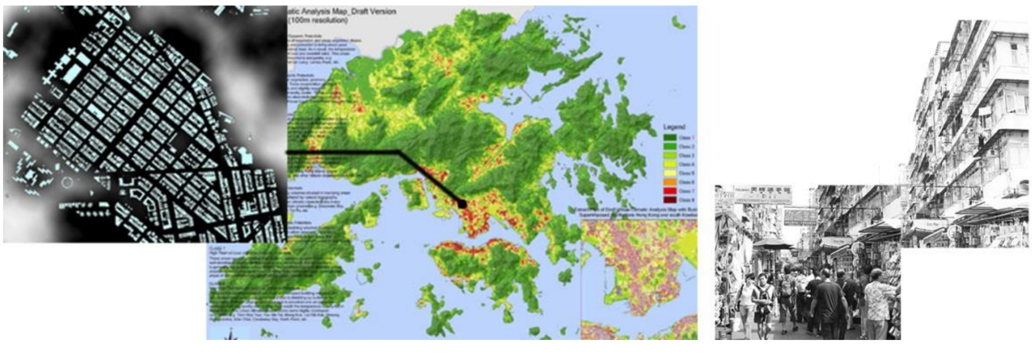

Figure 1 Locations of the selected sites showing on the Urban Climatic Map of Hong Kong (Ng et al., 2009) with the building layout (left) and street views (right).

METHODOLOGY

Site Survey and Model validation

This study considered approximately 1350000 m2 traditional residential areas with compact building block arrays in the SSP district. In the selected site, the total building volume was 16,722,000 m3 and the average building height was 32 m with a standard deviation of 15. The site is located in the waterfront areas, and wind from the sea dominates the district in the summer. Several building blocks are parallel to the summer sea breeze, whereas the others are tilted at approximately 45° (Fig.1).

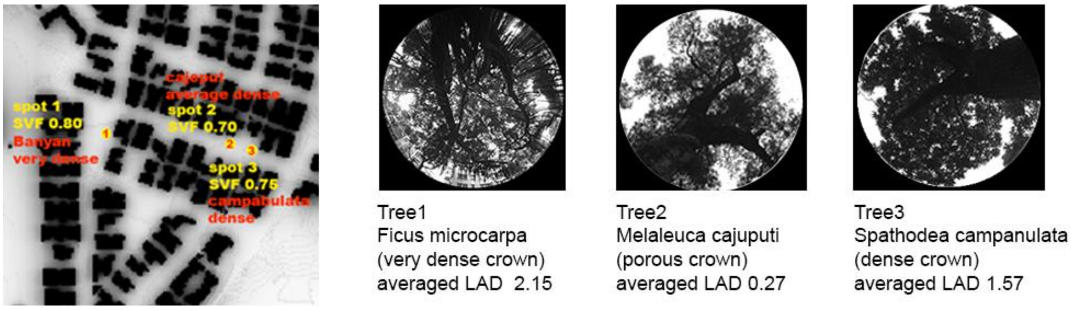

Figure 2 Building layout of the survey site and locations of the testing trees. The fisheye image of tree1-3 and the estimated LAD are also presented.

A small-scale site survey was conducted to determine the influence of tree crown configuration on the microclimate under tree canopies. The measuring site was a residential area with relatively low traffic; and the measuring period was between 13:00–14:00 on a clear sunny day in early July. The measured data were also used to validate the vegetation model of the ENVI-met program.

Fig. 2 shows the building layout of the survey site and the locations of three testing trees. The profile of leaf area density (LAD) of each testing tree was estimated based on fisheye images and the vertical configuration of the tree crown; and was inputted to the plant database in ENVI-met model for calculation. Thermal indicators were measured under the canopy of testing trees and a nearby (within 20 m distance) reference point exposed to sunlight using a TESTO measuring instrument, FLIR thermography camera and black globe thermometer. Table 1 compares the measured and simulated values on air temperature, surface temperature, and means radiant temperatures (Tmrt).

Table 1. Measuring result from the pilot study

	1. Ficus microcarpa		2. Melaleuca cajuputi		3. Spathodea campanulata	
	in shade	exposed point	in shade	exposed point	in shade	exposed point
Air Temperature	32.8 / 33.6	33.3 / 33.8	32.9 / 32.9	33.5 / 33.2	33.1 / 32.9	33.5 / 33.0
Surf Temperature	33.4 / 33.8	62.5 / 58.5	36.4 / 36.9	61.0 / 57.8	43.9 / 46.0	61.0 / 57.3
T_{mrt}	35.3 / 37.4	68.1 / 70.9	37.5 / 38.9	66.4 / 70.7	48.0 / 48.7	66.5 / 70.7

(Figures in black are the measured data and figures in grey are the calculated results. T_{mrt} calculated based on the measured data with the method of Thorsson et al. (2007), and by the ENVI-met model, respectively.)

Table 1 indicates that the model successfully reproduced the microclimate under tree canopies with various LAD and the thermal condition of reference points under the effect of urban morphology. The measured ground-surface temperatures were approximately 4° higher than the calculated results in the exposed points; this result can be attributed to the thermal property of the ground material. The surface material of the survey site is dark asphalt which would present relatively higher surface temperatur. Based on the data, it can be concluded that the ENVI-met model is a reliable tool for green design in urban areas and microclimate study under noontime high solar angle during summer in Hong Kong.

PARAMETRIC STUDY OF GREENING DESIGN

Based on the original building layout, the building morphology of the SSP site was simplified into aligned arrays and tilted blocks with uniform building height for the parametric study (fig.3). Urban trees that are 20 m high with averagely dense (average LAD = 0.15 m2/ m3 within the tree crown) and dense crowns (average LAD = 0.95 m2/ m3 within the tree crown) were planted in the aligned and tilted streets as shown in Fig. 3. The aligned streets were oriented at north–south and east–west to test the influence of orientations, whereas the building heights were set at 30 and 60 m to simulate low and high SVF conditions, respectively. These two values were selected because 30 m is the average building height in the SSP site and 60 m is the weighted average building height in Hong Kong as a whole. Therefore, greening design schemes are studied under SVFs ranging from 0.2 to 0.3 and 0.4 to ¬0.5. Cubes were set with uniform height at the model boundaries to simulate the effect of the surrounding morphology.

For simulation setting, 250*250*30 grids version was selected for model domain in the case study with grid sizes being 6m. The study focused on thermal comfort at the pedestrian level; hence, dense (four layers) vertical telescoping grids were set in the first 2 m to improve the accuracy of the results. Input wind data including wind directions and pedestrian wind velocity can be extrapolated down from the 500m height wind data of the SSP district and the wind profile power law expression (1).

$$u(z)/u_{ref} = (z/z_{ref})^{\alpha} \quad (1)$$

u(z) and uref represent the mean wind speed at a certain height z and at a suitable reference height and α is the terrain roughness at 0.15. The input wind speed was adjusted, and the wind speed at the aligned street was maintained at 2.7 m/s–3.0 m/s at a height of 2 m. The other meteorological input data are listed in Table 2, and these data were based on the averages obtained during hot summer days in August 2012 (data source: Hong Kong Observatory, SSP station). The total simulation duration was 8 h (from 6:00 to 14:00).

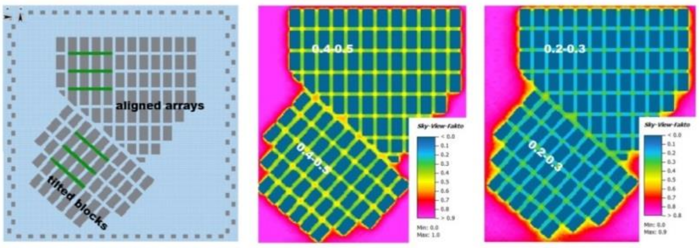

Figure 3 Simplified building morphology applied and the greening design scheme and two ranges of SVF values would be tested in the parametric stuy.

Table2. Input data used in the simulation

Initial Temperature atmosphere [K]	303	**Relative Humidity 2m [%]**	70
Heat Transmission Walls [W/m²K]	2	**Heat Transmission roof [W/m²K]**	2
Albedo Walls	0.2	**Albedo Roofs**	0.3

Data Analysis. This study investigates the effect of urban trees on the enhancement of outdoor thermal comfort under different morphologies. hence, the most critical daytime period in summer in subtropical regions was selected for analysis, which would be noontime and early afternoon when the solar radiation is intense and the surfaces have been heated up. In this study, simulation result in 13:00 (the early afternoon) is chosen. The efficiency of urban trees in differnet morphology settings is evaluated on the aspects of atmosphere and surfaces cooling. As a more comprehensive indicator for environmental impact for human comfort, the mean radiant temperature will also be investigated.

- 0.4-0.5 SVF (building height 30m)

In the first scheme, building height was set to 30 m. The cooling effect on the air and surface temperatures were also examined under SVFs ranging from 0.4 to 0.5. Fig. 4 depicts the simulation results for the two oriented base cases without greenery. Fig. 5 displays the reduction in the air and surface temperatures of trees with the variation in tree crown density when the aligned streets were oriented at east–west. The maximum magnitude of air cooling was 1.8 K in the middle section of the shaded area at a height of 1.5 m under dense tree crowns. The edge of the shaded section was cooled by 1.2 K and was reduced to 0.8 K approximately one block away in the downwind area. The greenery effect was slight on areas with tilted streets (0.5K) because wind speed is reduced. Given cases with averagely dense tree crowns, the cooling effect was roughly halved.

With respect to surface cooling magnitude, the shadowed areas on the ground were limited to the edge because the buildings were relatively short and because SVFs were high. Therefore, surface temperature distribution is quite homogeneous (40 and 45 K for aligned and tilted streets, respectively). The surface temperature was lowered by 5 K and 9 K in aligned and 9K tilted streets, respectively, given averagely dense tree crowns. Furthermore, the cooling magnitudes by denser tree crowns were 11 K and 17 K, respectively (Fig. 5). With the average dense tree crowns the mean radiant temperature under the tree canopy was about 49K and with dense tree crown the value was cooled down to 33K.

The efficiencies of the dense tree crowns (average LAD 1.0) were basically twice that of the averagely dense tree crowns (average LAD 0.2) in terms of cooling the air and surface and reducing the mean radiant temperatures. When the aligned streets were oriented to north–south, the reduction in air temperature by the street trees was basically similar to that in the east–west orientation. Moreover, the decrease in surface temperature was approximately 1 K lower in the east–west orientation for both aligned and tilted streets.

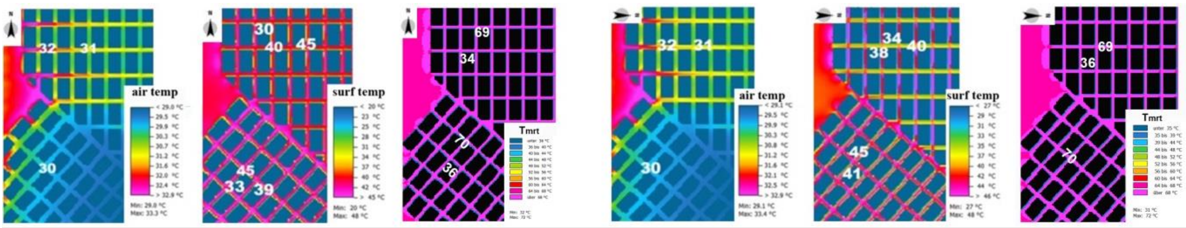

Figure 4 simulation results on on air temperature, surface temperature, and T_{mrt} for basecases of two orientations under high SVF (ranging at 0.4-0.5)

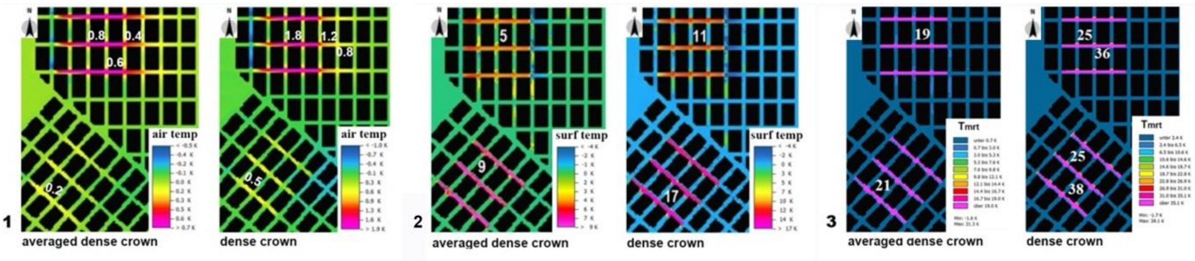

Figure 5 cooling magnitude of street trees compared to base case in 13:00 for high SVF scenario (aligned streets E-W oriented). (1) air cooling by averaged and dense tree crowns; (2) surface cooling by averaged and dense tree crowns; (3) T_{mrt} reduction by averaged and dense tree crowns

- 0.2-0.3 SVF (building height 60m)

In the second scheme, building height was set at 60 m. The SVF values of the streets at ground level ranged from 0.4 to 0.5. Fig. 6 shows the simulation result for the base case. The air temperature of the street at pedestrian level was lower and the shaded area of ground surface was larger than those in the 30 m scheme.

When the aligned streets were set to be east-west oriented, it can be seen that the cooling magnitude on air temperature was smaller than the larger SVF case, as depicted in Fig. 7, and with the shading of trees, the air temperature would be cooled down to similar level in the streets with SVF of 0.2-0.3 and 0.4-0.5. On the other hand, for surface temperature and T_{mrt} the cooling magnitudes were almost the same for high and low SVF scenarios; the cooling effect presented more various levels in streets with low SVF. The influence of crown configuration on cooling efficiency showed similar pattern, i.e. the denser tree crowns were more effective and for tilted streets, the thermal effect of trees was minor in air cooling but significant in cutting down the surface temperature and T_{mrt}.

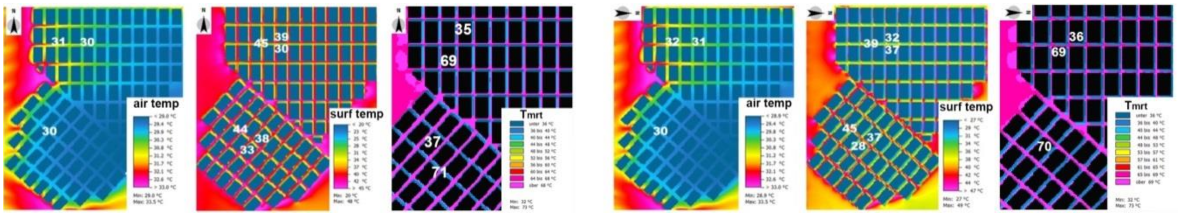

Figure 6 simulation results on air temperature, surface temperature, and T_{mrt} for basecases of two orientations under low SVF (ranging at 0.4-0.5)

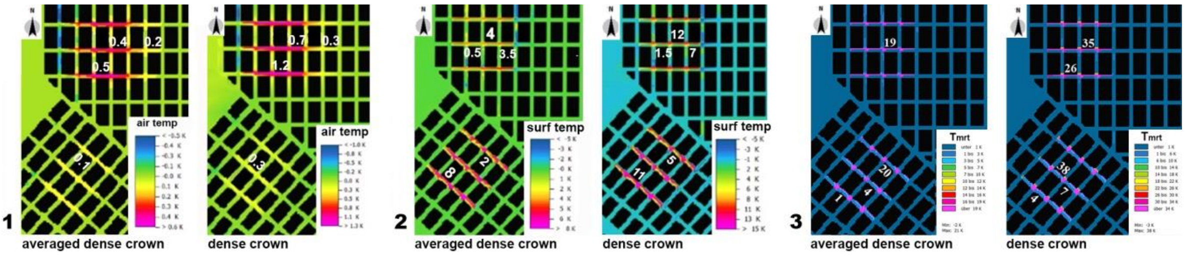

Figure 7 cooling magnitude of street trees compared to base case in 13:00 for low SVF scenario (aligned streets E-W oriented) (1) air cooling by averaged and dense tree crowns; (2) surface cooling by averaged and dense tree crowns; (3) T_{mrt} reduction by averaged and dense tree crowns

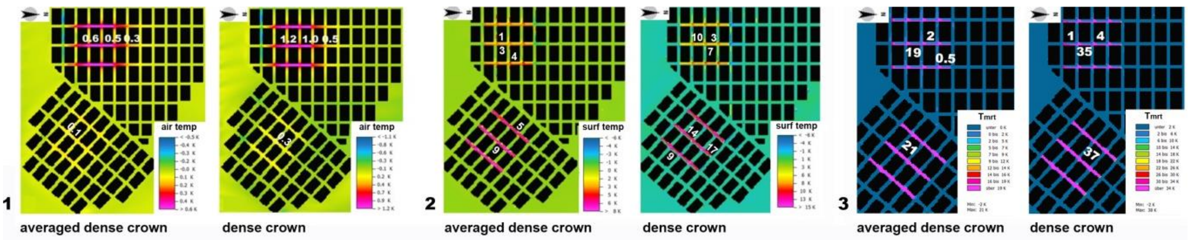

Figure 8 cooling magnitude of street trees compared to base case in 13:00 for low SVF scenario. (aligned streets N-S oriented) (1) air cooling by averaged and dense tree crowns; (2) surface cooling by averaged and dense tree crowns; (3) T_{mrt} reduction by averaged and dense tree crowns

Hong Kong is located south of the Tropic of Cancer. The sun casts shadows in two directions on aligned building arrays in the early afternoon during summer before, during, and after the solstice. The shadow on the ground is enlarged along with diversity in surface temperature and the radiative environment under low SVF. The shadowed area of tilted blocks was larger in the northwest–southeast streets than in the northeast–southwest streets. Trees in streets with low SVF will shade the ground surface and homogenize the temperature. The simulation results indicated that surface of the aligned streets oriented at north–south was less heated by 5 K at the center of the road than that oriented east–west. The difference was reduced to less than 3 K in streets with averagely dense tree. The surface temperature of aligned streets with dense trees was cooled to 30 K, and the surface temperature of the tilted streets was 28 K in either orientation. In addition, greenery cools the several "hot spots" generated at street crossing areas, as a result of building geometry and solar angle in the summer. The tree shading is most needed in these hot spots (fig. 7 and fig.8). For the mean radiant temperature, the cooling magnitude in the vegetated area was relatively more diverse under low SVF scenario, especially for north-south oriented streets. Based on the study of Forwood et al. (2000) in Sydney, it was revealed that the comfortable range for T_{mrt} was 24 to 30 degree. The simulation result showed with the averaged

LAD at 1.0 level, the T_{mrt} value under canopy was cut down to 33 degree for both high and low SVF environment, greatly improve the outdoor thermal comfort in the compact residential neighborhoods in subtropical Hong Kong.

CASE STUDY OF GREENING DESIGN

The green design scheme was tested using the existing building layout in the SSP area based on the parametric study results to investigate the thermal influence of trees on the urban environment further. The "aligned streets" in the site were oriented at northeast–southwest and were parallel to the direction of the local wind, whereas the "tilted streets" were oriented at east–west. Trees with relatively dense crowns (average LAD = 0.5) were planted in these streets (fig. 9). The simulation settings remained similar to those of the parametric study. However, the inputted wind speed data at a height of 10 m was adjusted to ensure that the wind velocity at pedestrian level was consistent with that in the parametric study.

Fig. 9 shows the building layout in the SSP site under the greenery design scheme, as well as the SVF and wind speed distribution in the simulation of the base case. Fig. 10 presents the magnitude by which air and surface temperatures are lowered by the street trees. The distribution of SVF and wind speed in the base case was complicated by the irregular building morphology in actual urban environments; and two two parameters are closely related to the air and surface temperature in the area.

The case study further confirms the findings from the parametric studies. The applied LAD in the case study was moderate compared with that adopted in the parametric study; therefore, the cooling magnitude was also at moderate level. With the LAD at about 0.5 levels, the trees reduced the T_{mrt} by about 28-30 degree and the value under tree canopy was about 34 degreee in the SSP neighborhoods.

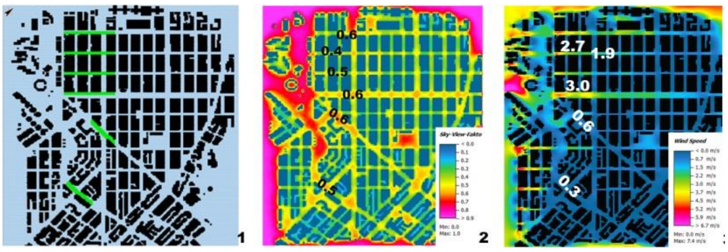

Figure 9 (1) greenery test scheme in case study with existing morphology in SSP site; (2) SVF distribution in the basecase; (3) wind speed distribution in the basecase

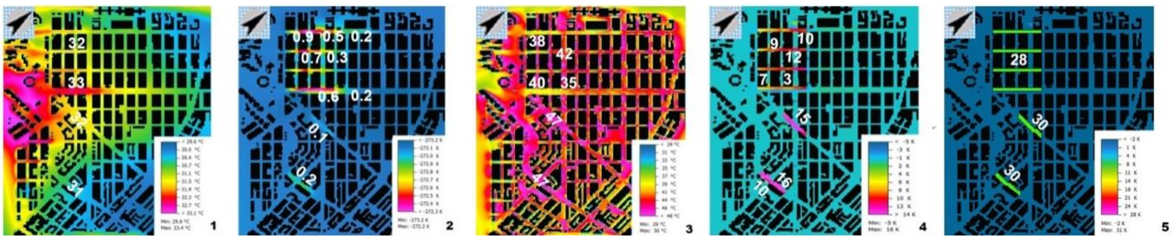

Figure 10 simulation results for case study of SSP site: (1) basecase air temperature distribution; (2) magnitude of air cooling by trees; (3) basecase surface temperature distribution; (4) magnitude of surface cooling by trees; (5) reduction of T_{mrt} by trees

SUMMARY

To address the problem of greening design for improvement of the outdoor thermal environment in high-density cities, parametric study and case study were conducted on compact residential building blocks in Hong Kong. The effects of tree crown configuration under varying SVFs and street orientations were tested by simulation with the three-dimensional microclimate model and ENVI-met. In this study, the cooling efficiency of urban trees in residential neighborhoods was evaluated based on cooling the air and ground surfaces, as well as mean radiant temperature reduction. Air cooling is dependent on the air velocity in the street, whereas the latter two indicators are morphology-related. Findings of the study can be summarized as below:

1. Influence on urban thermal environment varies with the crown density of urban trees. Tree crowns with an average LAD of above 0.5 are recommended for improving the outdoor thermal environment of high-density cities. In compact residential neighborhoods with street trees of this dense, cooling effect in air temperature and surface temperature would achieve 1K and 10K, respectively. With dense tree crowns of LAD averaged at about 1.0 level, the mean radiant temperature would be cut down to 33 degree under the canopy; given the hot summer in subtropical Hong Kong, it can be considered the urban trees provide a comfort microclimate for residents and greatly improve the outdoor thermal environment.
2. With respect to the influence of building geometry, the absolute cooling magnitudes of air and ground-surface temperatures were smaller in low SVF (0.2–0.3) than in high SVF (0.4–0.5) scenarios. The ground surface is exposed at varying levels in subtropical cities because of the high solar angle at noontime in the summer. Moreover, diversity in radiative environment would be enlarged as a result of builfing geometry. Street trees with certain LAD level could cool down the ground surface and even the thermal differences. And it is more critical to shade the street-crossing areas with tall dense trees to avoid overheat in high-dense neighborhoods with low SVF.

Nonetheless, this study has several limitations. First, additional environmental indicators should be included to evaluate the thermal effect of urban trees comprehensively. Second, the relationship between greening design and the thermal comfort of residents in the compact urban environment of tropical/subtropical cities should be further studied.

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Design Optimization of Vernacular Building in Warm and Humid Climate of North-East India

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ABSTRACT

Vernacular buildings are evolved through trial and error method over the period of time. These buildings are constructed more on 'design-based approach' suited to a particular climatic condition and socio-cultural setup rather than emphasizing technological solutions or prescriptive requirements. However, in recent times, due to quest for better thermal comfort, energy consumption is increasing in these naturally ventilated buildings. So, it is an urgent need to analyse the present level of thermal comfort and the occupant's expectation in these buildings. In case of design based approach, passive solar design, ventilation, insulation on the building envelope, shading and glazing area, proper orientation of buildings etc. are the key parameters for optimization process. In this study, a vernacular building of warm and humid climatic zone of North-East India is considered. Thermal performance study has been done by carrying out year long measurements of environmental parameters both at indoor and outdoor of the building along with thermal comfort survey and interaction with the occupants. The comfort and neutral temperature for different seasons of the year have been evaluated in the study. Solar energy modular simulation tool TRNSYS 17 is used to carry out simulations of the building. Building 3D model is generated in TRNSYS and design optimization has been done by carrying out parametric simulations for different scenario such as wall thermo-physical properties and thickness, window to wall ratio, glazing type, orientation, shading, infiltration, ventilation and internal load. The objective of the simulations is to improve the indoor thermal environment close to the comfort temperatures obtained during comfort survey. Indoor temperature profile of the optimized building shows significant reduction in number of discomfort hours compared to the base case.

INTRODUCTION

Vernacular buildings are the structures that use the bioclimatic concepts and locally available building material to a large extent (Singh et al., 2011b). This provides an edge to vernacular buildings to withstand with the local climate constraints through adaptation. However, vernacular buildings are mainly constructed on *design based* approach and evolve over the period of time through trial and error method (Ruiz and Romero, 2011; Singh et al., 2010a; Singh et al., 2010b; Singh et al., 2011b). These buildings attract attention of researchers because these structures represent an excellent harmony between environment, available building material and resources, socio-economic status and socio-cultural need of occupants, climate pattern and comfort, thus putting forth a unique example of sustainability (Kulkarni et al., 2011; Orehounig and Mahdavi, 2011; Singh et al., 2011b). In modern times, with the changing lifestyles, comfort standards and energy needs are increasing. Hence, it is important to look at the energy saving potential and sustainability presented by bioclimatic aspects of vernacular buildings (Singh et al., 2010a; Singh et al., 2010b). Vernacular buildings of North-East India are naturally ventilated and constructed using locally available building materials. Shape and form of these buildings are evolved over time to meet the socio-cultural and day to day requirements (Singh et al., 2010a; Singh et al., 2011b). These buildings are still favoured by people of the region and are still being widely constructed (Singh et al., 2010a; Singh et al., 2011b). However, in the present context of increasing comfort requirement and energy efficiency regulation and guidelines, it is an urgent necessity to carry out the thermal performance study of these vernacular buildings (Auliciems, 1981; Brager and Dear de, 1998). In this study, a vernacular house located in warm and humid climate (Tezpur, India) is considered. Selected house is modelled in TRNSYS 17 (*Transient System Simulation*), most widely used solar energy modular program to carry out the thermal performance study of buildings (Bansal and Bhandari, 1996; Beckman, 1994; Datta et al., 2001). It is a very powerful solar modeling and simulation tool (Bansal and Bhandari, 1996; Orehouning and Mahdavi, 2011). In this study, multi-zone building is integrated to simulation studio by Type 56. Number of studies has been carried out in different parts of the world on the thermal performance of modern buildings by using TRNSYS. However, no study has been done on the design aspect of the vernacular houses of North-East India. Thermal simulations are carried out to see the effect of different design features on indoor temperature. Based on the analysis of simulation data suggestions are made to improve the indoor temperature variation inside the house over the year.

Table1 Properties of the selected vernacular house

House details	Properties
Building type	Vernacular house (Local common name : *Assam type*)
Climatic zone	Warm and humid
Build up area (m^2)	94
Building material	Brick, cement, sand, plywood, asbestos sheet/wood, galvanized tin sheet
Ventilation type	Naturally ventilated
Temperature range	Summer temperature : Maximum : 30 – 35 ^{0}C; Minimum: 22 – 27 ^{0}C Winter temperature : Maximum : 25 – 30 ^{0}C; Minimum: 20 – 15 ^{0}C
Layout and orientation	Open layout, NW-SE
Relative humidity (%)	75 - 90
Altitude (m)	48
Elevation of building	4.8 m (floor to eaves 3.8m and ceiling to roof top 1m)

North-East India is classified into three climatic zones (warm and humid, cool and humid and cold and cloudy) and vernacular houses in each climatic zone possess distinct climatic responsive features (Singh et al., 2007). Table 1 and 2 present the specific details and building materials of the selected vernacular house in warm and humid climatic zone. Figure 1 presents the layout of the selected vernacular house in warm and humid climatic zone (numbers in the Figure 1 represent the zone number). It can be observed from Figure 1 that openings (windows and ventilators) are evenly distributed on the facade of the house. It is found that windows of the zone 2 and 3 are made up of wood with single glazing (30% of total window area). Ventilators are made up of wood with single glazing (35% of total ventilator area). It is found from the thermal performance study of the selected house that the maximum indoor temperature swing is 10 ^{0}C (Singh et al., 2010a). It is also found from thermal performance analysis that the house is more comfortable in pre-summer and summer season compared to pre-winter and winter season (Singh et al., 2009; Singh et al., 2010a). Figure 2 represent the 3D drawing created in Trnsys3D and Google SketchUp. In 3D model, window on exterior façade are constructed by adding all the windows on exterior wall of same zone (keeping the area same) to reduce the complexity of the model. Since the selected vernacular house is naturally ventilated so auxiliary heating, cooling and mechanical ventilation are kept off for all simulations. In case of naturally ventilated building indoor air temperature variation is the most important parameter so entire study is focussed on analysis of indoor temperature variation in different zones of the house. In this house zone 2 and zone 3 are occupied for maximum duration of time so due consideration is given to the temperature profile of these two zones.

Indoor temperature variation of base case is also compared with the data collected during thermal monitoring work carried out in 2008 to judge the accuracy of the developed model.

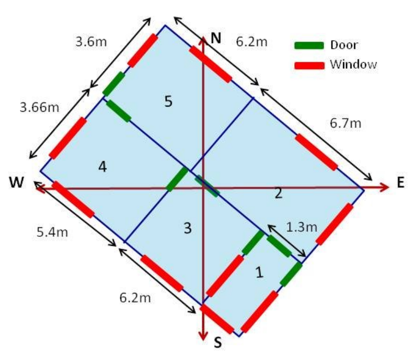

Figure 1 Layout of the house with different zones

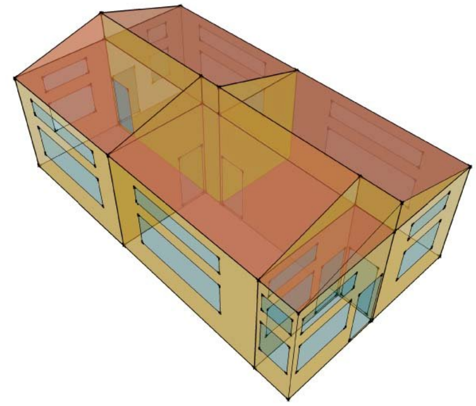

Figure 2 3D Drawing of the vernacular house

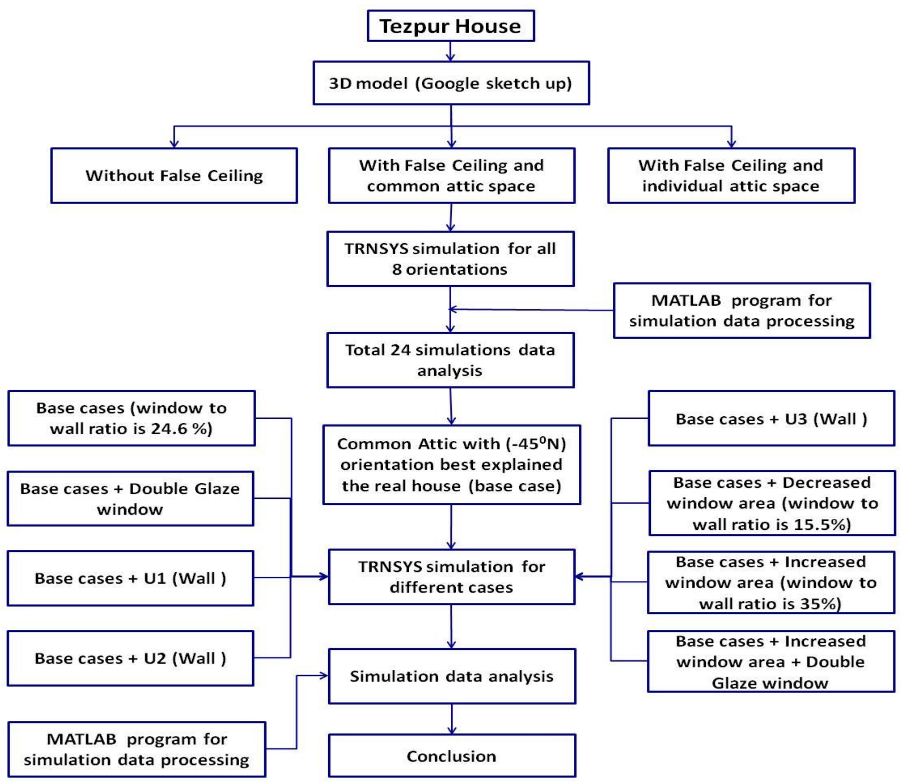

Figure 3 Methodology of the study

METHODOLOGY

Vernacular house in warm and humid climate is locally called Assam type in this region (Singh et al., 2011b). This build form is very popular and it has wide acceptance because it fits well into social-cultural setup, economical to construct, easy to maintain and above all meets the climatic constraints (Singh et al., 2011b). In modern times, with changing life style, demand for better comfort and energy use regulations is forcing occupants to explore different options that modify the indoor environment. Thus, it becomes necessary to study the design aspects of vernacular house for its energy efficiency. This enables us to understand the thermal behavior of the vernacular house with respect to design modification required in the building design. Figure 3 represents the methodology followed to carry out the present study. Parametric simulation studies are carried out by using TRNSYS and MATLAB simulation tool is also used to process the simulation data. Three different 3D models like without false ceiling, false ceiling with common attic space and false ceiling with individual attic space are made in

Google SketchUp. All these models are used to carry out the simulation for all eight possible building orientations. It has been tried to find out the best model by analyzing the simulation data which provides close result to thermal comfort survey data (Singh et al., 2010a; Singh et al., 2011a). This house is being selected as '*base case*' for further simulations with design modifications. Figure 3 also shows the seven cases for which the base case model simulation is carried out with design modifications. Table 3 presents the specific details of seven cases for which the simulations are carried out. The different scenario for the simulation are (i) applying different insulation to the walls of base case house (ii) replacing windows and ventilators with double glazing of base case (iii) increase and decrease the windows and ventilators area to base case (Table 2) (iv) replace the increased windows and ventilators area with double glazing to base case. The house considered for this study is naturally ventilated so the zone temperature is considered as the main output parameter along with zone heat gain due to infiltration. The infiltration is kept at 3 ACH (air changes per hour) for this naturally ventilated house for all simulation cases.

Table 2 Input parameters for base case building

Building materials	Thermal conductivity (W/m-K)	Density (kg/m^3)	Specific heat (kJ/kg-K)
Plaster	0.721	1762	0.84
Brick	0.811	1820	0.88
Tin sheet	61.06	7520	0.50
Asbestos sheet	0.245	1520	0.84
Wood(window, doors and ventilators)	0.17	900	1.7
Foam insulation (10cm) U1	0.144	1.4	10
Wooden wool (10 cm) U2	0.33	0.025	400
Mineral wool (10 cm) U3	0.16	0.90	80

Table 3 Wall construction and thermo-physical properties of materials with thickness

Case	Wall configuration		Over all heat transfer coefficient (W/m^2 K)	
	External wall	Internal wall	External wall	Internal wall
Base case+single glazing window with wooden frame	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm)	Plaster (1.5cm) + brick (11cm) + plaster (1.5)	2.103	3.056
Base case + double glazing window	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm)	Plaster (1.5cm) + brick (11cm) + plaster(1.5)	2.103	3.056
Base case + wall with insulation 1	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm) + insulation U1 (10cm)	Plaster (1.5cm) + brick (11cm) + plaster (1.5) + insulation U1 (10cm)	0.316	0.331
Base case + wall with insulation 2	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm) + insulation U2 (10cm)	Plaster (1.5cm) + brick (11cm) + plaster (1.5) + insulation U2 (10cm)	0.568	0.621
Base case + wall with insulation 3	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm) + insulation U3 (10cm)	Plaster (1.5cm) + brick (11cm) + plaster (1.5) + insulation U3 (10cm)	0.343	0.304
Base case + decreased window area	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm)	Plaster (1.5cm) + brick (11cm)+ plaster (1.5)	2.103	3.056
Base case + increased window area	Plaster (1.5cm) + brick (23cm) + plaster (1.5cm)	Plaster (1.5cm) + brick (11cm) + plaster (1.5)	2.103	3.056
Base case + increased window area + double glazing	Plaster (1.5cm) +brick (23cm) + plaster (1.5cm)	Plaster (1.5cm) + brick (11cm) + plaster(1.5)	2.103	3.056

BUILDING MODEL GENERATION AND SIMULATION

TRNSYS 17 simulation tool is used to model the selected vernacular house to study the energy flow in the house as well as in between the zones of the house. TRNSYS is a quasi-state simulation tool (Bansal and Bhandari, 1996; Beckman, 1994). Its modular structure provides a tremendous flexibility and facility to users to customise the generated model (Singh et al., 2009; Beckman et al., 1994). It runs through hourly values but user can reduce the time step according to the system requirement (Beckman et al., 1994; Singh et al., 2011b). A systematic approach has been adopted to develop a multi-zone model of the selected vernacular house in TRNSYS using TYPE 56. Type 56 in the simulation tool also provides a provision to give 3D geometric surface information as input for detailed radiation calculation. This increases the accuracy of the calculations. Using Trnsys3D and Google SketchUp 3D model, vernacular house specifying zones is created. Once the building is defined properly the building variable needs to be updated and linked to TYPE 56.

RESULTS AND DISCUSSION

The vernacular house in warm and humid zone is generally constructed in three different pattern such as (a) without false ceiling (room air is in direct contact with roof), (b) with ceiling and attic space is common (most common type of construction) and (c) with ceiling but individual attic space above each room (walls of the houses are load bearing). 3D models for above three types of construction of vernacular house is generated in Google SketchUp and TRNBuild and imported to simulation studio as Type 56 (multi zone building). The simulations are carried out for all 8 possible orientations (0^0 due North, 45^0, 90^0, 135^0, 180^0, 225^0, 270^0, 315^0). The build up area of the selected vernacular house is 94 m^2**.** Figure 1 presents the configuration (numbers in the Figure 1 represent the zone number) of the house viz. zone 1: veranda, zone 2: living room/bed room, zone 3: bed room, zone 4: kitchen and zone 5: store room. Based on the functionality and specific requirements of rooms in a vernacular house, zone numbering is done in the selected vernacular house. Subsequently analysis of the simulation data has been carried out keeping in mind the requirement of the zones. In this study, due consideration has given to the temperature profile of zone 2 (living room/bed room) and zone 3 (bed room). Detailed thermal comfort model is applied by defining the geo-position. Thermal comfort, operative temperature and mean radiant temperature are calculated at the centre of each zone to analyse the thermal comfort. Since the selected house is naturally ventilated, heat gain/loss due to infiltration over 24 hours for entire year is also studied.

Simulation data of zone 2 and 3 of the house with no ceiling, ceiling with common attic and ceiling with individual attic is analysed. It is found that the house with no ceiling show higher daily indoor temperature swing. Also roof of all the house is made up of galvanised tin sheet, so it gain and loose heat quickly. This happens because indoor air in this house is in direct contact with roof and in day time it gains heat inside quickly and loose heat quickly in the night time. It is also observed that temperature fluctuation remains high for most part of the year except for the last three months when daily temperature swing is less. This can be explained by observing the local wind velocity profile. Low wind velocity greatly affects the infiltration and natural ventilation. Again looking at the indoor temperature swing of house having ceiling with common attic and ceiling with individual attic, it can be found that difference is very less. Hence, it can be concluded that the house with individual ceiling shows slightly better thermal performance but considering the complexity of construction and safety this can be neglected (Assam lies in seismic zone V). Hence the house having ceiling with common attic has been considered for further study.

Table 4 Indoor temperature range from field measurements and simulation of zone 2

Climatic zone (place)	Month	Range of indoor temperature (°C)	
		Field measurement and comfort survey	Simulation
Warm and humid (Tezpur)	January	13 - 23	13 - 22
	April	22 - 28	22 - 29
	July	27 - 34	27 - 33
	October	22 - 28	23 - 29

Figure 4 and 5 presents the daily maximum and minimum temperature variation for zone 2 of the simulated vernacular house for all orientations. Similar kind profiles are also obtained for zone 3 of the selected house. It is observed from these figures that in pre-summer and summer the orientations has no effect on the indoor maximum and minimum temperature profile of the selected vernacular house. This is because in naturally ventilated vernacular house infiltration is very high. However, in pre-winter and winter months, it is found that that zone 2 and 3 of the house show some variation in the indoor temperature depending on the orientation of the house. The effect is more visible in the minimum temperature profile of zone 2 and 3. The reason of this behaviour can be attributed to the change in solar altitude angle and exposure of different zone of the house at different orientation. The orientation of real house at Tezpur is 315^0N (i.e. - 45 ^{0}N if the building is rotated anti clock wise). It is found that at this orientation, zone 3 (bed room) is showing better thermal performance than zone 2 (living room/ bedroom). Hence, it can be concluded that the orientation of the vernacular house is wisely selected. The maximum duration of wind direction in this climatic zone is from south, south-east and south-west. Hence, zone 2 and 3 of the selected house are in the line of the wind in summer months. It can also be concluded from Table 1 that in this climatic zone summer season will be uncomfortable due to persisting high temperature and high relative humidity. Natural wind direction is used wisely in this case to minimise the discomfort due to high relative humidity. Large openings in the form of window and ventilators on the external façade of the house is also promoting cross ventilation. Table 4 shows the comparison of indoor temperatures range between the field measurements and simulation of zone 2 of the building for base case.

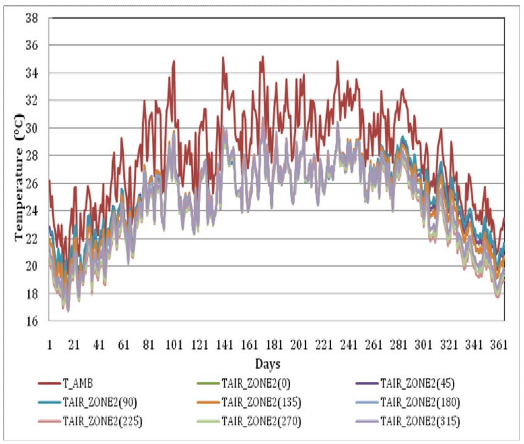

Figure 4 Daily maximum temperature profile of zone 2 of the selected house with common attic

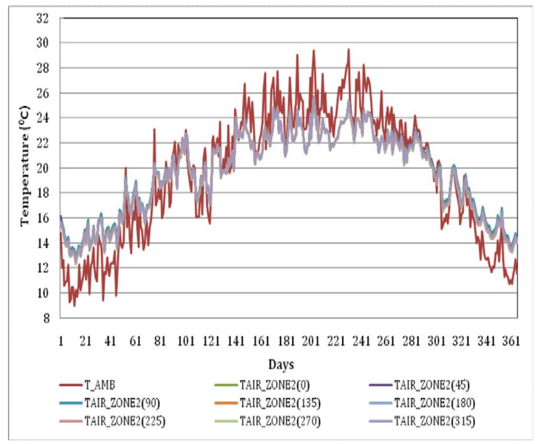

Figure 5 Daily minimum temperature profile of zone 2 of the selected house with common attic

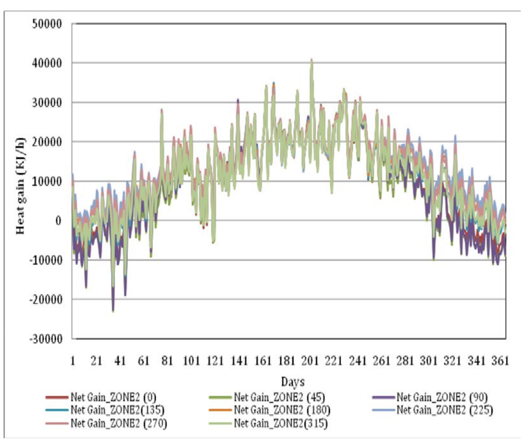

Figure 6 Daily total heat gains due to infiltration in zone 2 of the selected house with common attic

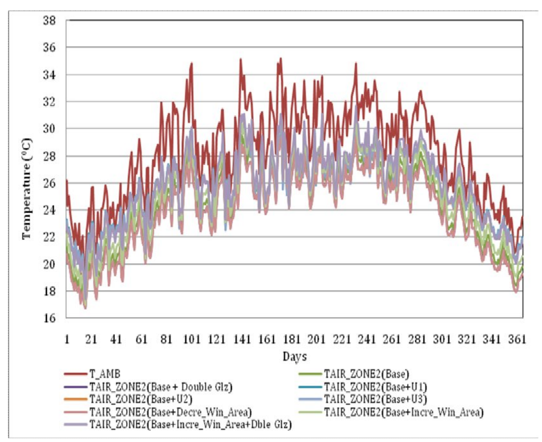

Figure 7 Daily maximum temperature in zone 2 of the selected house with different cases

Figure 6 represent the heat gain/loss due to infiltration in zone 2 for different orientations. It is observed from this figure that the present orientation of the selected house is the best option because in winter heat loss due to infiltration is less compared to other orientations. It is found that in summer there is a large heat gain due to infiltration and this may be one of the reasons for high indoor temperature and subsequently discomfort. In summer, it is expected to minimise the heat gain by operating windows and ventilators during day time and increase heat loss in night (night ventilation). Night ventilation can be enhanced naturally by opening windows and ventilators fully thus allowing maximum infiltration of outside air. This can also be achieved by using mechanical ventilation at night. This will reduce the discomfort duration in summer considerably. To avoid discomfort due to heat loss in winter, the main activity should be to increase the heat gain and minimise the heat loss. Here also if opening and closing of windows and ventilators are regulated intelligently then discomfort due to cold can be minimized to a large extent. So, it is found that large window to wall area ratio in existing vernacular houses can be used intelligently to overcome the climatic constraint and consequently increase comfort duration in this vernacular house.

Based on the above analysis, vernacular house of base case is selected (with common attic space and orientation 315 ^{0}N) for further simulations. The various scenarios considered for the simulation are listed in Table 3. Figure 7 and 8 represents the daily maximum and daily minimum temperature profile of zone 2 respectively. Similar profiles are also obtained for zone 3. It is observed from these figures that increase of insulation has minimum effect on the indoor air temperature profile of zone 2 in summer season. This happened due to high infiltration minimises the effect of increase in insulation. It is also observed from Figure 7 and 8 that increase in window area with double glazing leads to increase in daily maximum and minimum temperature in summer and winter season. However, the increase is more prominent in winter season. This happened due to low altitude of sun in winter helping sunlight enters directly inside the rooms through window glazing leading to increase in indoor temperature supported by better insulation properties of double glazing. Figure 9 represent the daily temperature swing in zone 2 for different cases. It is observed from Figure 9 that when insulation is applied to the inside wall of the building, the indoor temperature swing becomes high compared to base case. The reason for this can be attributed to the low inertia of the insulation and also insulation is not allowing energy stored in the external wall to radiate to indoors. Low thermal inertia and high infiltration is responsible for large temperature swing. This situation may lead to discomfort in indoors if insulation is applied to naturally ventilated buildings. Hence, it can be concluded that the base case is the best option with respect to the daily indoor temperature swing of zone 2. Similar results are also obtained for zone 3.

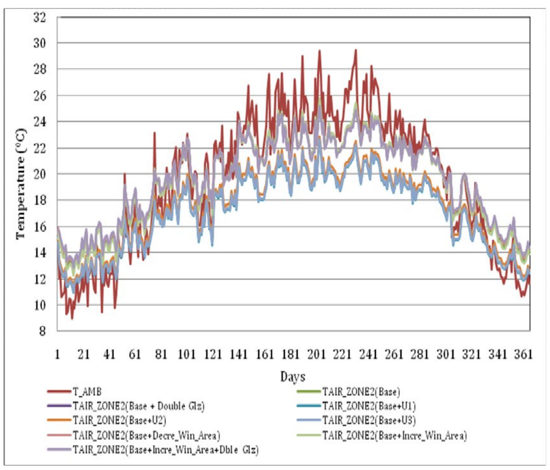

Figure 8 Daily minimum temperature in zone 2 of the selected house with different cases

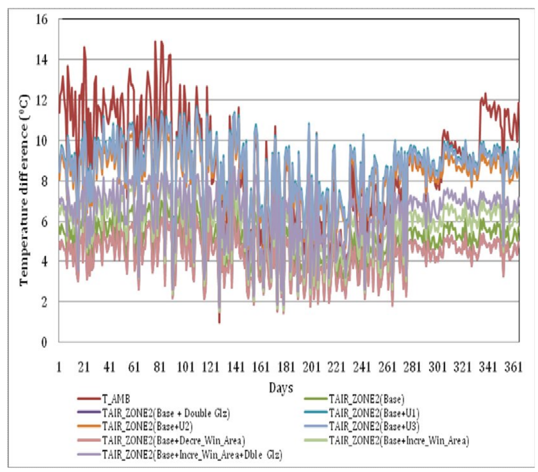

Figure 9 Daily temperature swings in zone 2 of the selected house with different cases

It is also observed from Figure 9, that decrease in window area case is showing lowest swing in daily indoor temperature profile. However, this cannot be suggested as best design option, as it will also drastically reduce the day lighting level and natural ventilation which will lead to discomfort. In all the cases, high indoor temperature swing is observed from January to June months as during this period wind velocity is high, which enhanced the heat gain and loss due to high infiltration. It is found from the Predicted Mean Vote (PMV) and thermal model analysis, that these houses show low thermal comfort in winter and summer months (Singh et al., 2010a; Singh et al., 2011a; Singh et al., 2015). However, they show acceptable thermal comfort in pre-summer and pre-winter months. Simulation results also show that zone operative temperature is always lower than zone air temperature by 1 – 1.8 ^{0}C and zone meant radiant temperature is always lower than zone operative temperature by 1.2 – 1.8 ^{0}C throughout the year. Similar trend is also observed for all other cases also.

CONCLUSIONS

In this study, vernacular building of warm and humid climate zone of North East India is considered for design based thermal optimization by using the simulation tool TRNSYS. It can be concluded based on the analysis that the house having ceiling with common attic is showing acceptable daily indoor temperature swing. It is also found that the vernacular houses of this zone must have ceiling to minimize the daily indoor temperature swing. It is found from the analysis that due to high infiltration in naturally ventilated building, insulation has almost negligible effect on the daily indoor temperature swing. However, it is found that increase and decrease of window and ventilator area has significant effect on the daily indoor temperature swing (window and ventilator area is most sensitive building design parameter). It also can be concluded from this study that increase and decrease of glazing area has maximum effect in the winter season when the sun altitude is less. Hence, it can be recommended that if the window be replaced with double glazing with proper shading mechanism then the indoor thermal conditions will be significantly improved. Thermal comfort analysis shows that buildings are thermally more comfortable in pre-summer and pre-winter season. However, this study needs to be further carried out by integration of airflow model with thermal model to obtain better results.

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The Climatic Design in Chinese Vernacular Courtyard House Settlement – A Wind Environmental Simulation

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ABSTRACT

The application of Chinese vernacular courtyard environment adaptability design strategies in Chinese contemporary architectural design are becoming more popular among Chinese architects. Starting from the climate consideration in architectural design, using CFD simulation to understand the wind environment in the Chinese traditional vernacular courtyard and settlement based on North China climate conditions (taking Beijing as an example). Firstly, the wind environment in the original courtyard building settlement is simulated. Secondly, parametric studies on the effect of width-to-length ratio (W/L) and north building height-to-south building height ratio (H_1/H_2) on the wind environment in courtyard house are conducted. Finally, several variants of courtyard house are also tested. This study is consummating the deficiencies of previous similar studies and digging the key points of how the same architectural form provide wind environment adaptability in different seasons with totally opposite weather conditions.

1. INTRODUCTION

With the development of building technologies, from 1950s, unified building forms of modernism (internationalism) swept the worldwide building industry and have been squeezing the survival space of the regional and vernacular buildings with traditional forms not only on cultural and aesthetic aspects but also on environmental aspects (Frampton, 1993). More dependence on unified modern building technologies leads to less local climatic considerations in architectural design. As building indoor environment is now universally conditioned by the HVAC system, energy consumption becomes higher and higher. In China, more than 1/3 of the total energy consumption directly derives from buildings. Considering both the severe global environmental situation brought by high energy consumption and the environmental quality needs from building occupants, the concept that to achieve better environmental quality, higher performance and more sustainable building by exploring climatic considerations and environmental strategies in the conventional vernacular building form has been put forward and got wider recognition (Givoni, 1998; Olgyay & Olgyay, 1963). As one of the most typical, conventional architectural forms-courtyard house was adopted in many contemporary architectural design by architects in China. The reason is that courtyard house has perfect climatic adaptability, especially with its natural ventilation and thermal environmental performance (Blaser, 1995).

Although ‘learning from tradition’ is generally recognized among architects, the climate adaptability of those new architecture design based on tradition can hardly be achieved without drawing the ancient wisdom into the new building design in the right way and suitable place. The courtyard house is one of the most widely distributed architectural forms in China. By adjusting the shape (such as changing the aspect ratio, building height etc.), this form can easily be adapted to totally different climate conditions. Therefore, it is essential to know how different types of vernacular courtyard can be adapted to different regional climate. Using a specific courtyard shape in a wrong place or only forming a ‘seemingly the same’ enclosure space will not work or will even make thing worse.

In this paper, computational fluid dynamic (CFD) simulations will be conducted for achieving better understanding about the wind environmental design characteristics of the Chinese vernacular courtyard and settlement based on North China climate conditions (taking Beijing and its specific courtyard form-‘Siheyuan’ as the example). Related parametric studies will be conducted for consummating the deficiencies of previous studies on similar topic.

1.1. Climatic Condition in Beijing

Beijing is located in northern hemisphere warm and semi-humid continental monsoon, which can be regarded as the typical representative city of the North China. Climate characteristics of Beijing can be summarized as follows: In winter, it is dry and cold, the mean temperature is approximate -2℃; in summer it is hot, sometimes humid, the mean temperature can achieve 26℃ or higher; in spring, it is warm and dry; in the fall which is the best season of Beijing, the temperature falls and the sunlight is bright (CMA, 2006). It can be observed that under Beijing’s climate condition, high air temperature with relatively high humidity will reduce both the indoor and outdoor thermal comfort level in summer if there is no enough ventilation; and in winter, the cold temperature climate condition will trial the building wind-protection and insulation performance.

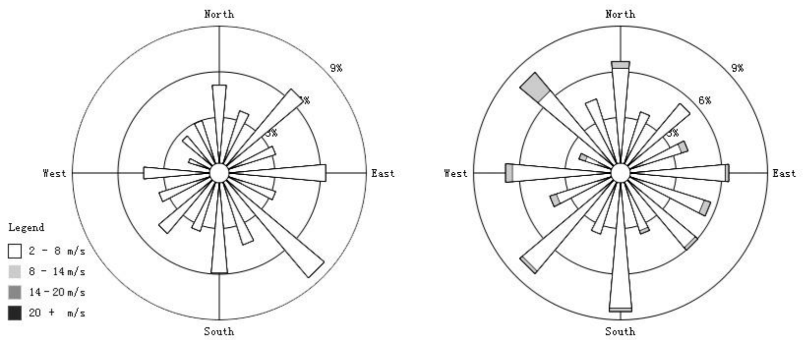

Figure 1 *Summer time (left) and winter time (right) wind rose chart of Beijing.*

As to the wind, what can be seen from Figure 1 is that during the summer, highest frequency wind direction is from southeast (135°, N = 0°), the average wind speed is approximate 5.5m/s. In winter, frequencies of winds from different directions are relatively uniform. However the worst condition - highest frequency of excessive wind speed appears at direction of northwest (315°), in which the wind speed can reach 8.0m/s or even more. High wind speed which exceeds the wind comfort threshold of peoples will decrease both the indoor and outdoor thermal comfort, meanwhile put negative influence on peoples’ activities (Penwarden & Wise, 1975).

1.2. The Vernacular Courtyard in Beijing - Siheyuan

The courtyard is a central opening enclosed by buildings which is the most basic elements for Chinese traditional built environments, including cities, houses, and gardens (Xu, 1998). The vernacular courtyard house (also called ‘Siheyuan’ or ‘Chinese quadrangles’) is a conventional type of residence, which was widely adopted throughout the North China (Figure 2).

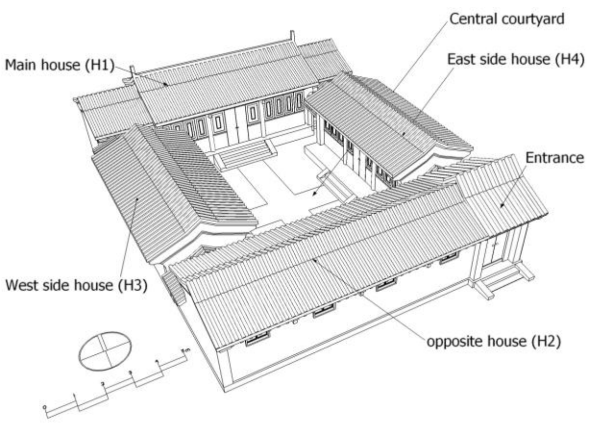

Figure 2 *Typical and the most basic layout of Beijing courtyard house with one central inner courtyard space.*

2. LITERATURE REVIEW ON PREVIOUS STUDY

In worldwide, many studies on CFD simulation for vernacular buildings in different climate regions have been conducted. However, regarding to the traditional courtyard in North China, although there are a lot of research and practice on the architectural design issues (such as spatial design, cultural context inheritance and heritage conservation, etc.), there are only two studies on the wind environment based on CFD simulation. In the first study (LIN, WANG, ZHAO, & ZHU, 2002), the effects of different courtyard shapes on their wind environment were tested based on only four different simplified "box" models without indoor space, the conclusion are descriptive not quantitative. Another study which focus on the wind environment in a single courtyard house was conducted by the author (SHI, 2013), which is the initial part of the study shown in this paper. The previous study draws the conclusion that the optimized courtyard shape should has the width-to-length ratio (W/L) of 1.0 and the north building height-to-south building height ratio (H_1/H_2 in Figure 3) of 1.2-1.4; when the overall amplification of courtyard building scale is three times of the original scale or more, appropriate precautions on wind-proof design must be taken to keep the pedestrian level wind environment comfort around the building. However, these results are acquired based on the simulation for a single courtyard house model without surroundings (Figure 3). Instead of the single courtyard house model, this study will validate the previous conclusion based on a courtyard array model and also take more design parameters into consideration. Therefore, this study can be regarded as the extension and also the improvement of the previous one.

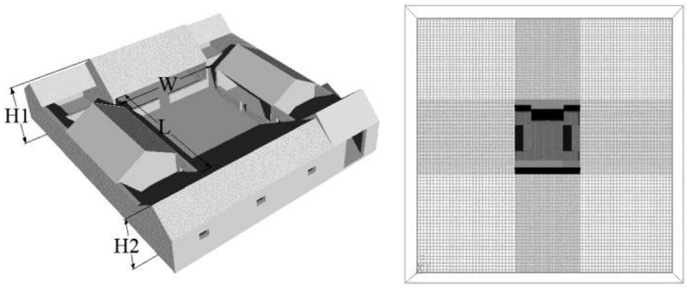

Figure 3 *The single courtyard house model and the simulation domain used in previous study (Source: (SHI, 2013)).*

3. WIND ENVIRONMENT IN TRADITIONAL VERNACULAR COURTYARD HOUSE

Reynolds-averaged Navier-Stokes (RANS) equations with standard K-ε turbulent flow model is used to simulate the wind environment of the traditional vernacular courtyard house. The most basic courtyard house form in Beijing, which has one single inner central courtyard, is taken as subject investigated. The wind velocity field inside and around the courtyard house is studied with CFD simulation to understand the climate adaptive design strategies.

One important thing should be clarified about this simulation study is that the buoyancy effect is not taken into account at this stage. It is true that buildings are receiving certain solar radiation, which will lead to spatial temperature difference thus affect the whole pattern of air movement. However, for the courtyard house in cold regions of North China, the thermal mass of buildings is considerable. Therefore, the air movement due to the temperature difference is relatively insignificant compare with the air movement due to building geometry.

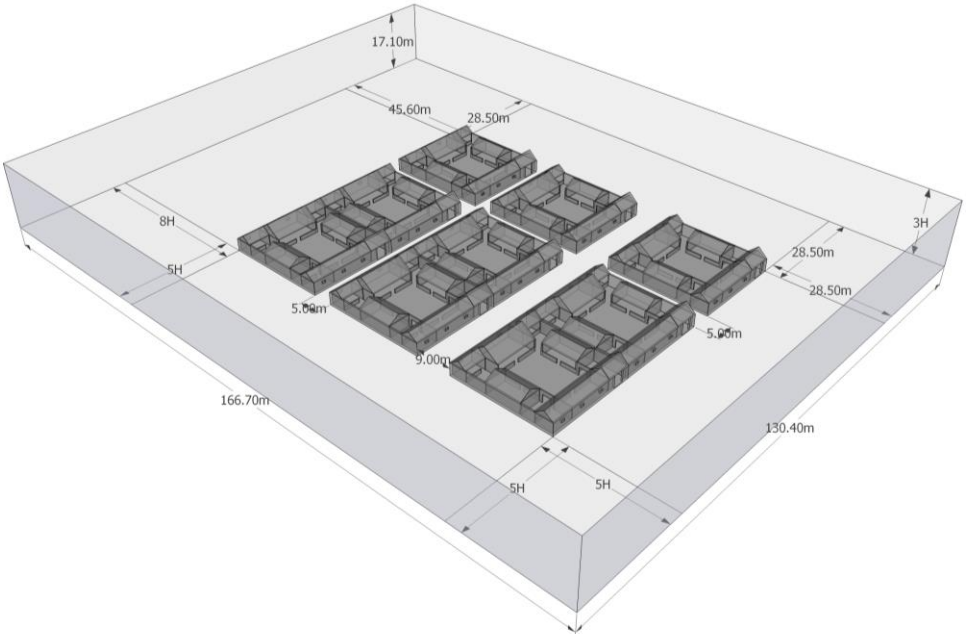

Figure 4 *The courtyard house array model and the simulation domain used in this improvement study. Where H is the building top height of a single courtyard house in this array model.*

3.1. Physical Model and Simulation Setting

As mentioned, the simulation and parametric study are based on a courtyard array model (Figure 4). Simulation was conducted under summer and winter condition separately. The distance between courtyard houses (street width) is set based on the traditional urban texture of Beijing old cities (WANG, 2007). Following the climate analysis in Section 1.1, for summer time simulation setting, the initial temperature is 26℃, the wind condition is 5.5m/s with southeast direction based on the prevailing wind condition; and for winter time setting, the initial temperature is -2℃, the wind condition is 8.0m/s with northwest direction based on the most negative condition for thermal comfort and building wind-protection. Initial wind environment is generated based on the logarithmic wind profile with a reference height of 10m. At first, the wind environment in the original courtyard building settlement is simulated. Then, parametric studies on the effect of width-to-length ratio (W/L) and north building height-to-south building height ratio (H_1/H_2) on the wind environment in courtyard house are conducted. Finally, several variants of courtyard house with different entrance direction are also tested.

For all simulations, both under summer and winter conditions, the wind speeds mean value and maximum value of all inner courtyard and indoor spaces in the courtyard house array is calculated and taken as the evaluation index. Therefore, for one type of courtyard geometry, there are total four indicators of wind speed.

3.2. Wind Environment in the Original Courtyard Building Design

Figure 5 (left) is the wind environment in a courtyard house array in the summer time. In summer, the average wind speed in all inner courtyard space of the house array at the 2m-height position is about 2.0m/s under the background wind with a speed of 5.5m/s at 10m-height, which can provide satisfying natural ventilation. In winter time, Figure 5 (right) shows that the average wind speed of all regions of the nine courtyard houses at the 2m height position still keep the level of 2.5m/s, even the maximum wind speed is lower than 4.0m/s under the background wind with a speed of 8.0m/s at 10m-height.

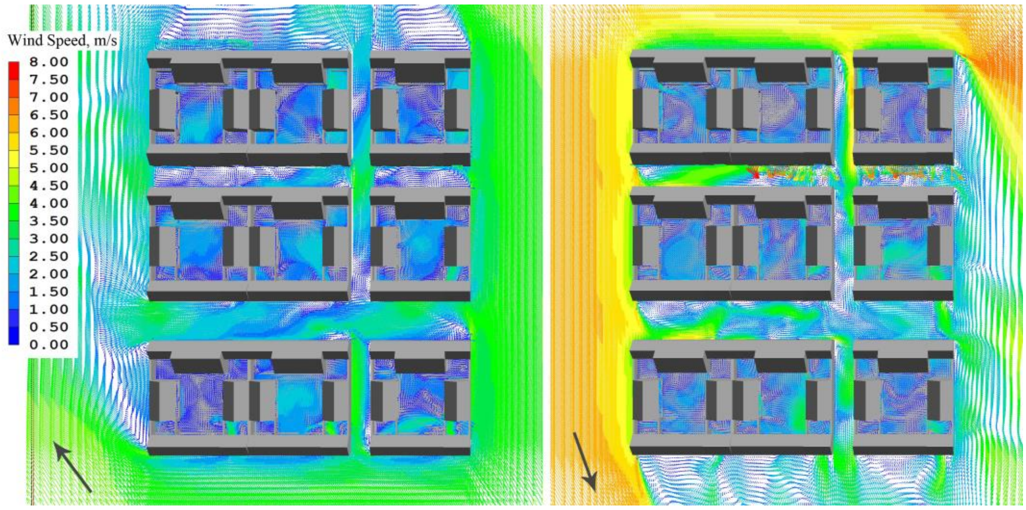

Figure 5 *Wind environment simulation results: wind velocity field at the 2m height level (m/s) in courtyard house array in summer (left) and winter (right).*

4. FURTHER PARAMETRIC STUDY BASED ON PREVIOUS RESEARCH

4.1. The Width-to-Length Ratio (W/L)

Wind environment in five courtyard house array models with different W/L ratio (range from 0.5-2.0) under summer and winter condition were simulated separately. Figure 6 shows the parametric simulation results comparison. Compare with the simulation of a single courtyard model, the overall wind speed for whole parametric test decreases, but the trend keeps unchanged. Taking the W/L ratio of 1.0 (original ratio of basic conventional courtyard house) as the baseline, what can be observed is that increasing the W/L ratio will slightly increase wind speed in the courtyard both in summer and in winter, but the effect of wind speed change on people is non-significant; when decreasing the W/L ratio, the wind speed is increased distinctly. In a courtyard where the W/L is equal to 0.5, even the maximum wind speed reaches the comfort threshold. Therefore, when architects attempt to design an enclosure courtyard space, quadrate shape whose W/L ratio approximates 1.0 is preferred. Long and narrow space along with the prevailing wind direction should be avoided.

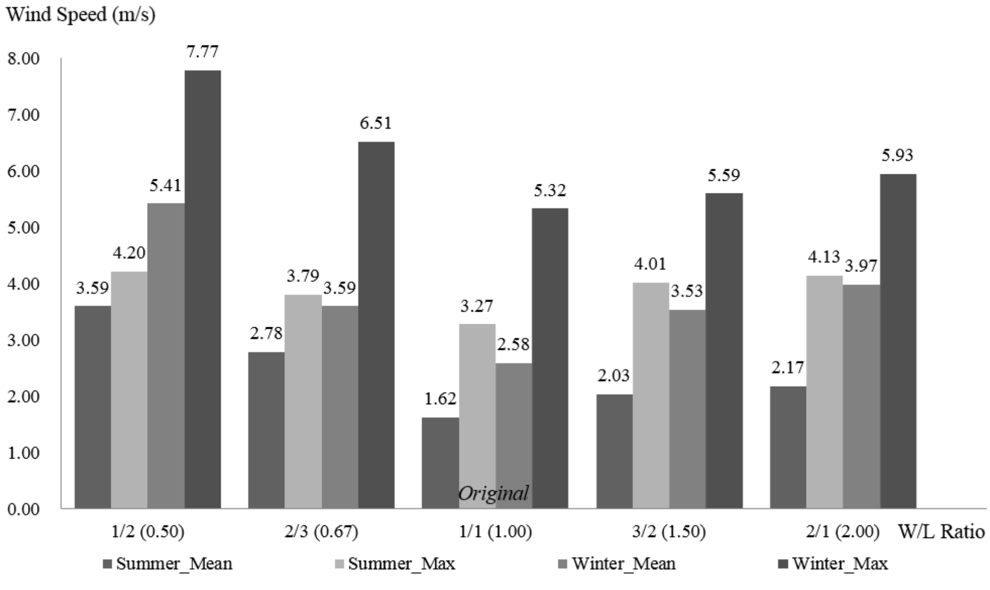

Figure 6 *Comparison of wind speed in inner courtyard space with different W/L ratio (m/s).*

4.2. The Building Height Layout (H_1/H_2)

The second parametric study is regarding to the building height layout. Considering the prevailing wind direction both in summer and in winter, the north building height-to-south building height ratio (H_1/H_2) was selected as the variable in this parametric study.

Six different H_1/H_2 ratios are simulated for comparison range from 1.0 to 2.0 under both of summer and winter condition (Figure 7), taking the original H_1/H_2 ratio of conventional courtyard house (1.2) as the baseline. Under summer condition, courtyard arrays with the H_1/H_2 ratio of 1.2, 1.4 and 1.8 have basically same performance better than others (H_1/H_2 = 1.0, 1.6 and 2.0). They have appropriate average wind speed for ventilation, and meanwhile the peak value doesn't affect peoples' activities negatively. However in winter, the H_1/H_2 ratio of 1.8 have maximum value of wind speed which will decrease the thermal comfort level and increase the heating energy consumption. Thus, the H_1/H_2 ratio from 1.2 to 1.4 is the preferred choices for designing courtyard space.

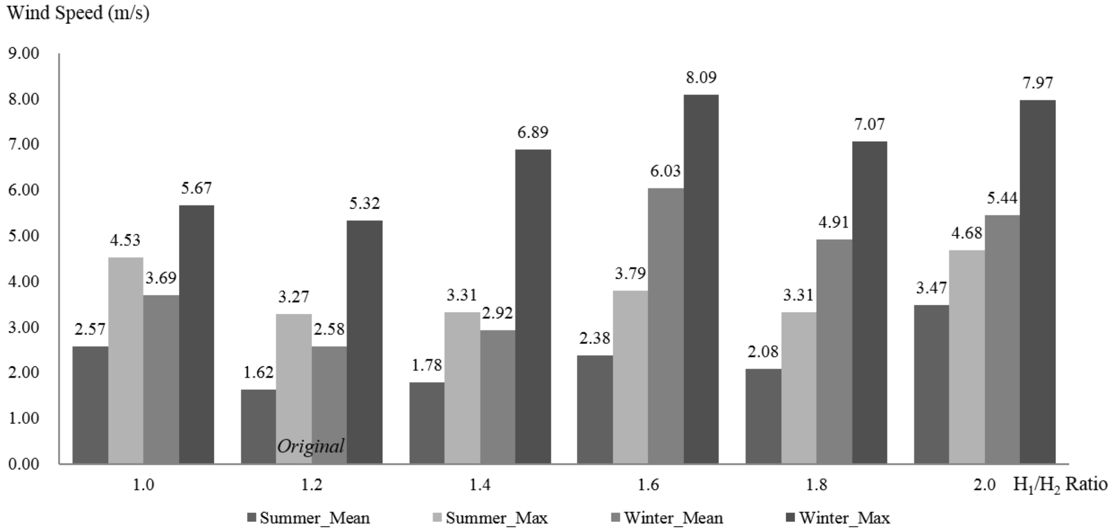

Figure 7 *Comparison of wind speed in inner courtyard space with different H_1/H_2 ratio (m/s).*

Above simulation study results based on basically validate the correctness of previous simulation based on the model of a single courtyard house that the optimized courtyard shape should have the width-to-length ratio (W/L) of 1.0 and the north building height-to-south building height ratio (H_1/H_2) of 1.2-1.4. There are some feedbacks on the previous study query that why the roof shape is not taken into consideration. The answer is that the roof shape of courtyard house was designed based on the daylighting (especially the accessibility of sunlight in winter) and summer shading, which is not the main factor of wind environment design.

4.3. Different Variants of Courtyard House

Although most Beijing courtyard houses are built to follow the basic layout that the overall orientation along north-south (positioned in the north and facing south) and four buildings of a courtyard house are arranged along the north-south or east-west direction and the main entrance are located at the southeast, there are still different variants of courtyard house (MA, 1999). The most commonly seen variation is the adjustment of the main entrance location (shown in Figure 8).

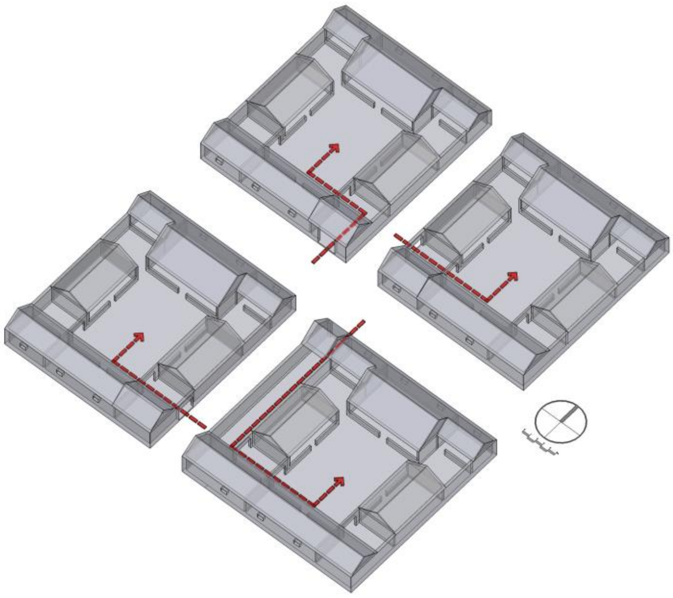

Figure 8 *Several most commonly seen variants form of Beijing courtyard house. The basic layout doesn't change, but the location of main entrance are different (Source: Based on (MA, 1999)).*

Using the same setting with above simulation, a courtyard house array model consists of four different variants of the courtyard house with different entrance location are simulated. Figure 9 shows the simulation results. The results show that the difference among four kinds of variants of courtyard house is also non-significant, which means that the entrance location is not the main impact factor of wind environment in courtyard house buildings. To further explain, in winter time, even the entrance has the same direction with winter time prevailing wind, by adding an additional corridor, the wind speed in the inner courtyard space still can be kept in the comfortable range of building occupants.

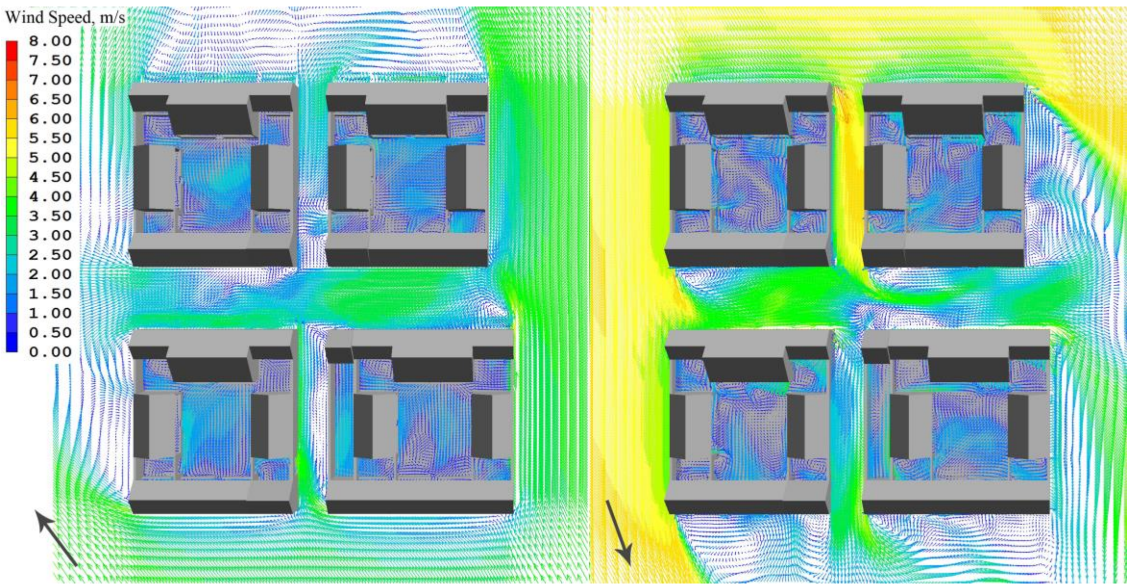

Figure 9 *Simulation results of the most commonly seen variants form of Beijing courtyard house: wind velocity field at the 2m height level (m/s). Left: summer time, right: winter time.*

5. CONCLUSION AND DISCUSSION

This study improves the previous study on the bioclimatic architectural design of the Chinese vernacular courtyard building. The optimized courtyard shape which has the width-to-length ratio of 1.0

and the north building height-to-south building height ratio of 1.2-1.4 is validated by the parametric study based on a new created Beijing courtyard houses array model. The simulation for several variants of courtyard house also shows that the location of courtyards' main entrance will not affect the wind environment in the central courtyard space, if appropriate design measures are conducted.

In the section 3.1, the author implies that higher wind speed is preferable in summer. Nevertheless, higher wind speeds are not chosen from results shown in Fig. 6 and 7. The reason is that for a residential building designed under climatic conditions with significant seasonal variation, it is important to make a balance between different needs in different season. It this case, both higher wind speed in summer or lower wind speed in winter is essential for a comfortable wind environment. Therefore, the trade-off has been made when determining the optimal choice.

By understanding the key impact factors of wind environment in the courtyard house building form, architects can apply this vernacular architectural form and its climatic adaptability strategies into the environmental building design properly and wisely. This study focus on the influence of the building geometry, therefore, more future works will be conducted on the thermal aspects for comprehensive understanding of vernacular building climatic design strategies.

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Demystifying vernacular shop houses and contemporary shop houses in Malaysia; A Green-Shop Framework

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ABSTRACT

Vernacular shop houses in Malaysia have been thoroughly studied to understand their significance in environmental, cultural, economical and heritage values. UNESCO recognition in 2008 has further secured shop houses conservation works in Malaysia (UNESCO, 2008). However, contemporary shops in Malaysia do not share similar concerns of preservation and cultural significance. Popular view has perceived contemporary shop as lacking of both cultural and building performances standards. Thus, this research testifies the cultural and building performances in both contemporary shops and vernacular shop houses through cross-content analysis onto Malaysia Uniform Building By-law (UBBL), Green Building Index (GBI) and Special Area Plan (SAP). This research aims to critically investigate the correlation between vernacular and contemporary shop houses to develop a guideline strategy for green performance in shop houses. Through re-learning of vernacular shop house design and critical examination of governing policies, this research had highlighted some design issues that affects today practices. Policies are exploited to users' interpretation that contributes to poorly built shop houses that have neither green nor cultural significance. This framework developed three distinct yet complementary areas in a bid to explore various green strategies and important criteria, which are building envelope design, green design, and cultural design to identify the correlation between green performances and cultural sensitive buildings. Hence, this research provides fundamental guides to portray future potential of high performance shop architecture in Malaysia.

1. INTRODUCTION

Vernacular shop house (Malay: rumah kedai) is one of the unique architecture found in South East Asia particularly in Malaysia and Singapore built from 17th to early 20th century (Chen, 2007; Wan Ismail, 2005). The unique Chinese form of shop houses resulted from local influences and colonial's modification in an attempt to adapt to tropical climates. Vernacular shop houses follow Chinese rules of thumb in architecture which are symmetrical (Hong, 2009), narrow layout, and air-well in between spaces (Wan Ismail, 2005). Contemporary description has defined a vernacular shop house as 'built single, double or triple storey building' (Mohd. Baroldin & Mohd. Din, 2012) with measures of 6 to 7 meter width and depth of 30 meters and it could extend up to 60 meters (Haromshah, 2009). However, these attached buildings are not built simultaneously but over the time, adjoined together (UM-NUS Joint Studio Programme, 2009). Singapore Governor Sir Raffles altered the Chinese shop house's structure in 1822 by imposing five-foot ways (a covered pedestrian arcade) to accommodate wet weather in the region (Wan Ismail, 2005, p. 28; Abdul Mohit & Sulaiman, 2006). Furthermore, in late 19th century, backlanes for shop houses were required to allow accesses for sanitary and fire preventive measures, yet, had been reduced to limited use of rubbish collection in contemporary practice. Nonetheless, these changes have contributed to today unique shop houses physical forms. However, there are no evidences of continuous improvement to shop physical structure to adapt to present needs since mid of the 20th century. Hence, shop houses should revamp their present conventional structure to enhance the building performance toward greener design in a parallel response to sustainable development.

1.1. Shop houses development to present

Conservative organisations such as Georgetown World Heritage Inc. (GTWHI) and Badan Warisan have recognised heritage importance of shop houses that are dated back to before early 20th century (Figure 1). Mass developed shop houses after 1960's are perceived as non-cultural importance (Figure 2) and categorised as contemporary shop houses. Since the 17th century, shop houses went into a series of evolution that represented the Chinese and hybrid cultural influence. The evolution or transitional changes are part of the process of adaptation of climates, local cultural, economic demands and fashion influence. Shop houses were popular urban fabric during the 19th century to the early of the 20th century because of socio-economical advantages (Chen, 2007, pp. 90-91).

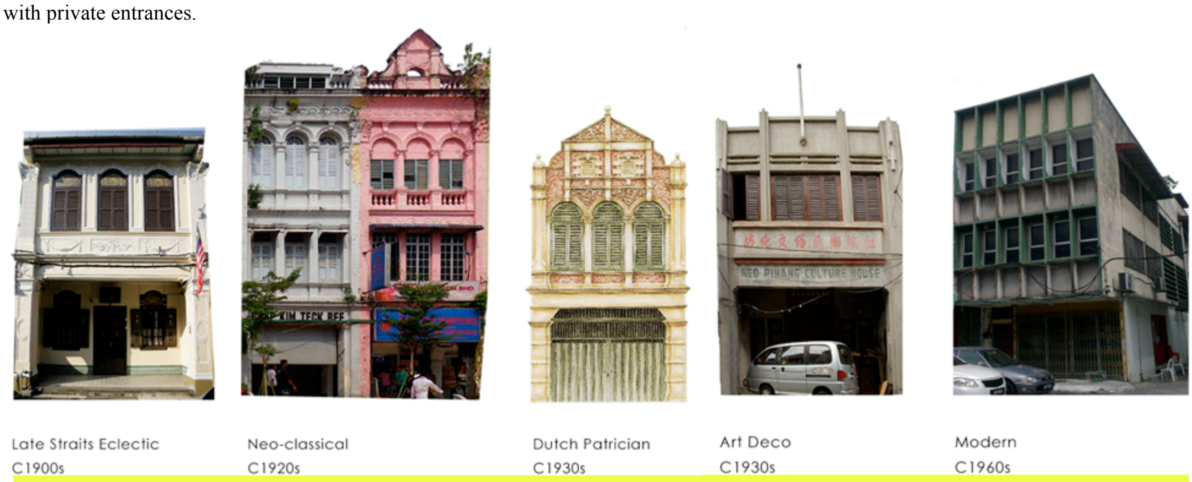
It is only found in Malacca. It is constructed with Dutch brick and lime plastered with timber structured roof. Simpler façade and symmetrical windows. It has one or two storey for residential use. Unlike other shop houses, Dutch styled shop houses are not connected with front arcade but confined with private entrances.

Earliest Chinese influenced shop houses found in Malacca city. The shop house embedded the notion of Chinese symbolism to promote spiritual harmonies. The structure is built with lime plastered brick and timber roofing. The architecture has close assembly to Chinese shops in southern China.

Simpler shop house follow the Southern China style. Normally built as double storey with connected pedestrian arcade. Earlier style has smaller form and façade, constructed with timber. Masonry party walls are adopted.

Minimal decoration display with decorated air-vent located below upper floors window. Continuous timber shutter design topped with Chinese decorated gable roof. Brick and lime plaster and unglazed roof tiles is widely used.

Adapting Malay, Indian and European influences. Yet, ornaments are still limited in use but certain designs are adopted such as pilasters, arch windows, and keystones. New materials have been adopted such as glass and concrete, although timber is still widely used in construction.



Ornaments flourished with strong European influences. Shop houses employing tripartite arrangement windows. Decorative ceramic tiles are used and European decorative plaster molded to form bouquet and festoon shape on the façade. Timber is decreased and replaced by reinforced concrete.

Buildings are decorated with classical elements such as pediment, moulded plaster and colonnade. Shop houses have abandoned timber construction and opt for masonry built. However, timber pitch roof is still practiced in the construction.

Dutch-inspired gable was adopted for the facade of this shophouse.

Source: Chen V. F. (2007), pg 90, Dutch Patrician.

Geometrical shape inspired and few decorative that is limited to extended parapet and flat pole. Embedded building date as part of the decoration. Adaptation of Shanghai plaster for façade treatment and concrete shading devices.

Reinforced concrete has fully adapted into building construction and abandoned timber as structural material. The trend further influenced contemporary practices without ornamentation but large flanks of overhang and shading design.

Figure 1: Timeline depicts shop houses facade transition is influenced by socio-cultural and political changes. The facades show different materials used ranging from timber to concrete through the global technology advancement

The stylistic of shop houses have hybrid characteristic incorporating architectural vocabulary from the West, Chinese and Malay. However, the adaptation to the Western design was only popular after local exposure to the culture in late 19th century. Revival styles such as Neo-classical and Palladian in the 1920's and 1930's (Pile, 2009, p. 432) prompted this fusion design. The revival styles are more acceptable than modernism, although both were popular during the early 20th century. Hence, the built form fashion could be integrated into local identity (Abel, 2000) are of trans-cultural significance (Presas, 2005). Regrettably, shop houses that adapted modernism later in the 1960's have not been classified as of historical significance because it lacks these unique characteristics of earlier shop houses and were continuously diluted by mass development. Moreover, contemporary shop houses are scarcely retained in original forms because of heavy modifications that resulted in difficulty to identify transitional forms in present architecture. The continuous modification of buildings structure is evidence of contemporary poor understanding of users' needs.

Figure 2: Classification of contemporary shop houses based on authors' research and observation

1.2. Shop houses as everyday architecture

Shop houses are simple buildings that do not stand as landmark or are of structural significant in urban definition. Their contemporary development and contribution to urban coherence and socio-cultural is poorly understood. Mass development is controlling the number of shop houses development in today urban fabric. However, studies found that this typology of everyday architecture is highly significant towards cultural development in heritage towns (Davis, 2006). Hence, contemporary shop houses would leave their marks onto Malaysian architecture and urban context that critically shaped the future of regional development.

In contrast, the formations of vernacular shop houses have encapsulated everyday life and place identity (AJM Planning and Urban Design Group , 2011). The unique shop houses structures have remarkably shaped earlier part of many cities with Chinese settlements (Chen, 1993) in Malaysia. Collectivity (Terraced shop houses) of "individual" shop houses with distinctive embellishment has enhanced the language shared within the urban taxonomy. Shop houses constructed forming several rows have increased their significance as a cluster of buildings that shapes local community life. These buildings could not function as singular entity; despite of their building performances (Davis, 2006, pp. 236-237). Therefore, contemporary shop houses should be critically re-examined to ensure the significance of shop houses continuously upheld as unique everyday architecture in Malaysia.

2. Evolution of Shop Houses in Malaysia

Contemporary shops in Malaysia are evolved from shop houses that dominated the urban landscape in the 19th and early 20th century. These retail buildings are significant in shaping local socio-economic aspects and formed parts of contemporary urban fabrics. The continuous development of new neighbourhoods or towns would observe shop houses as part of the common fabric for general small commercial activities in townscape and neighbourhood development (Maleki, et al., 2012).

Policies restriction and socio-cultural acceptance play roles in how shop houses perform to fulfil community needs. The notion of shop houses being green architecture is not bound within the set of physical structure but is correlated within policies and regulation and their impact on socio-cultural aspects. Encouragement and support from authorities are needed to promote greater energy efficiency and sustainable building among public users (Yang, et al., 2014).

2.1. Locality and Regionalism in Architecture

Shop house evolution lies within the acceptability of local towards foreign culture. The emphasis on foreign culture acceptability and adaptability to local identity is important to understand socio-cultural value in building performances. The relationship between architecture and its surrounding is simply an understanding of a place by oneself to create local identity (Abel, 2000, p. 143). Thus, architecture is the tangible resource of place identity that is influenced by socio-cultural aspects. The context of place identity is not only encased within socio-cultural aspect but as a holistic understanding of the place including climatic and topographic issues (Perera, 2013). Lee et al (2013, p. 604) identified place identity as reflection of local activities and its physical environment. The cultural importance, however, is only shown onto relevance and appropriation of "correct" culture that will enhance functionality and provides sense of orientation (Pelletier, 2012). However, in present shop house environment, buildings and its space has foregone the regional identity with globalised and homogenised image (Abel, 2000, p. 190). Kaye (1991 , p. 31) described the dilapidating of local shop houses as "hollow out of tradition", emphasising the idea of empty shop houses' façade.

Hence, regional orientated contemporary shop houses could transform the building into contextually appropriate, instructive and encouraging as locally unique and functioning architecture (Too, 1990). Lewis Mumford summarised that regionalism is not preserving the past or imitating but to recreate the same cultural value that are encapsulated in vernacular architecture onto new buildings that represent contemporary community (Lefaivre & Tzonis, 2001). Thus, the notion of regionalism in Malaysia is to celebrate the local identity (Day, 2004, p. 238) and localise the modernity development in the country. Regional designated shop houses should be climatically responsive to enhance building performances (Ozkan, 2006, p. 108). Hybrid designed vernacular shop houses are learning examples of adapting foreign architecture to form local community identity (Abel, 2000) for contemporary practices. These shop houses will continue to readapt the changing norms of the society and practices. Hence, successful contemporary shop houses could adapt foreign elements to enhance aesthetic, functionality and building performances without sacrificing local identity.

Concomitantly, the notion of modernisation would contribute into greater understanding of social problems that could be addressed with modern knowledge. Technology advancement and greater standardisation system could be beneficial towards improved design with enhanced understanding of material properties, construction methods and users behaviour.

2.2. Shop Houses and Urban Space

In view of a good urban environment is a precondition for a good quality of life, the quality of that area (urban) is a reflection from buildings and minor developments within the boundary. These physical developments besides being functional should incorporate cultural identity, green initiative and efficiency. Mass developed standardised contemporary shop houses have disrupted the urban patterns (Said, et al., 2013) with monotonous façades they have intimidated other surrounding buildings. The destruction of community identity is in-search for new "signature" and enforces this synthetic image to represent the local identity (Kaye, 1991).

Shop houses have encompassed other urban functionality in Malaysia including socio-cultural and economic importance. Street activities around shops area such as daily greengrocer market, weekly night market and community events that priorities local need (Ja'afar, et al., 2012; Lee, et al., 2013) and plays a major role in the public realm. The daily street activities are essential practice to form community conscience, which stimulates cultural identity and economical advancements in the area (Day, 2004). However, the sense of community would not be sustained without strong physical evidence in urban fabrics (Ujang, 2012). Contemporary shop houses are lacking in the physical attribution towards local cultures and community uniqueness (Said, et al., 2013, p. 422). Researchers (Samadi & Mohd., Yunus, 2012; Said, et al., 2013) have suggested that modernisation development should preserve the cultural images to maintain the consistency of urban character.

3. METHODOLOGY

This research is employing qualitative content analysis (QCA) in demystifying shop houses changes in physical design with socio-environmental influences. Similar researches were conducted in researching particular theme from documents as shown in Beharrell (1993) and Airken (1998) study (Bryman, 2008, p. 557). The significant of QCA is to produce wider and in-depth meaning from textual data by interpretation and relating it to the conducted research. This research would adapt relational analysis to explore and critically examine the relationship (Williamson, et al., 2003) of green building performances, socio-cultural aspect and shop physical design. Similar research was conducted onto shop houses in Singapore (Tut, 2011). In this research, source of data would draw up from three significant building standards, which are Malaysia Uniform Building By-law (UBBL), Green Building Index (GBI) and Penang's Special Area Plan (SAP).

UBBL is Malaysia building regulation law that administer all building construction standards in the country. Their minimum requirements would be generalised in this research as fundamental criteria for building construction. On the other hand, GBI is a non-compulsory rating system in Malaysia that is tailored to suit the country's climate (Tan, 2009). GBI would be the yardstick for both types of shop houses in green performances. Lastly, SAP is a draft regulation in Penang for protection of heritage buildings. SAP allows this research to identify details of construction methods, material and structure of vernacular shop houses. The identified criteria would be expanded and analysed. Therefore, through the three manual of regulations, authors would narrate keywords pending to physical regulatory and environmental input such as ventilation requirements, indoor comfort and greenery obligation. The cultural aspect would draw up from SAP by general coding keyword and requirement such as original materials, cultural words and shop houses. The coding of the three manuals would identify significant set of criteria of the Malaysian regulation standards that correlates to agencies commitment towards building performance and green design.

4. RESULTS

UBBL is drafted as preliminary law to regulate the built environment industry that draws up by architect's council in 1984 (Ministry of Housing and Local Government Malaysia, 2012). UBBL was drafted based on local buildings by law and British building regulation to unify the standards in building construction. Many of these standards in UBBL are following either local Standard Specification (LSS) or American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) regulation to provide optimal quality in building construction and internal comfort.

On the other hand, SAP drafted by GTWHI complies with UNESCO requirements in conserving the world heritage town (AJM Planning and Urban Design Group , 2011). SAP claimed to be championing the improvement in quality of life, derived from economy progression and developing sustainable and conserving heritage city (2011, pp. 6-1). The dynamic vision of SAP is fundamental notion that portray positivity that could be adopted in this proposed green framework. Thus, analysis of SAP would identify on how local cultural sensitive design incorporates into contemporary practices. In addition, SAP is in line with other building regulations and laws, which includes UBBL to avoid legal contradiction. SAP depends on UBBL to provide building standards such as fire regulation, building height and ventilation requirement.

Lastly, GBI Non-Residential New Construction (NRNC) guideline released in 2009 is used as reference towards green performances. NRNC is derived from 51 requirements under six criteria; energy efficiency, sustainable site planning and management (SM), water efficiency, material and resources, indoor environment quality and innovation. In addition, Township guideline Version 1.01 is used to identify the cultural and green significance within urban context. Township guideline has 45 requirements that encompassed climate, energy and water, environment and ecology, community planning and design, transportation and connectivity, building and resources, and business and innovation. GBI Township is strongly focused on social and economic value with promoting the drive force for local business, amenities and housing facilities. Hence, Township guidelines would correlate the socio-economic aspects with local environment to produce green urban development.

Table 1: Cross Case Analysis of UBBL, SAP and GBI requirements

Criteria	UBBL	SAP	GBI	Remarks
Physical Design				
Building Physical constraints	Building depth and width is not specifically mentioned but building width shall not fall less than 20 feet (ft.) according to Concannon 1951 ruling	N/A	N/A	Typical vernacular shop houses have 13-20 ft. (width) and depth expand from 30-60 ft.
Building Height (ht.)	Section 44 (3): Shop house ht. shall not be less than 10 ft. for ground floor and 8.4 ft. for any upper floors. No storey restriction.	Sec. 4.4: Building ht. shall not be higher than 18 meter (m) or 5 storey ht.	N/A	Vernacular shop houses have 12-18 ft. ht. or 1-3 storey ht.
Air-well	Section 40: Minimum requirement for 2 storey requires 7 square meter (m^2), subsequently each floor is entitles to 1 m^2	Sec. 6 Item 9.0: Air-well shall be maintained as part of the design with flexible roof to allow day lighting and natural ventilation	NRNC EQ8: Skylights are encouraged to promote day lighting in building design	Vernacular shop houses have 1 to 3 air-wells separating internal spaces depending on building depth with optional rear court feature
Five Foot Way (verandah-way)	Section 38: Verandah-way shall not be less than 2.25 m with 600 mm depth columns. Ramp (gradient less than 1 in 10) or staircase (minimum 150 mm riser x 275 mm treads) to level the adjoining units	Sec. 6 Item 2.2: Commercial activities shall not obstruct pedestrian use. Verandah-way dimension shall abide to local regulation	Townscape CPD and TRC: 75% of linked pedestrian walkway shall be covered to promote pedestrian scheme	Vernacular shop houses have 5 ft. depth or less verandah-way
Accessibility	Universal Design (UD) is required for disabled accessibility. The designates section is also covered pedestrian prioritised for verandah-way	Public space sharing is emphasised to encourage pedestrian scheme in verandah-way	Township CPD: Emphasising UD to accommodate disabled users with pedestrian network (TRC4) and open spaces	Car park facilities should expand to accommodate contemporary use
Staircase	Section 112: staircase for shop with direct access from street shall be enclosed with incombustible materials. Opening shall be provided at each landing for ventilation except building that is less than 3 storey could be unventilated	Sec. 5 Item 12: Staircase shall be built close to air-well for ventilation and abide to UBBL regulation on material use	N/A	N/A
Party Wall	Party wall shall not be less than 200 mm thickness (thk.) with masonry or in-situ concrete	Vernacular shop houses have thicker party wall (300 mm thk.) sharing between units as fire preventive measurement.	N/A	N/A
Green Design and Socio-Cultural				
Building Material	Section 53: All material shall abide to fire preventive and material safety endorsed by MS Standard. However, green materials are not included, assuming other regulation to be used	Material is restricted for roof and finishes (lime plaster and tiles) in preserving urban coherence.	NRNC MR: Recycled and green certified materials with regional sourcing to reduce unnecessary carbon footprint in transportation	N/A
Indoor Air Quality (IAQ)	ASHRAE and MS standards are applied to regulate IAQ through mechanical or natural ventilation. Under ASHRAE Standard 63-73: building shall provide 0.14 m^3 of air per minutes (cm) per occupant. Thus, any room shall have opening not less than 15% of total floor space with exception in Section 41 (mechanical ventilation)	Ventilation depends on passive design through air-vent, air-well, rear court, jack roof and facade opening design	NRNC EQ: IAQ shall abide to ASHRAE Standard 62 in regulating ventilation system to prevent harmful pollutants and mould. Natural ventilation is optional criterion provided that effective air exchange is set.	N/A
Thermal Comfort	Building that exceed 4000 m^2 shall require to have overall thermal transfer value (OTTV) less than 0.4 W/m^2K. However, typical shop houses does not require to but must abide to ASHRAE Standard 55	Passive cooling combined with lightweight structures to reduce thermal mass and heat gain	NRNC EQ6: Accorded to ASHRAE Standard 55	Kwong et al. (2014) claimed ASHRAE Standard 55 would create unnecessary internal cooling.
Energy Efficiency	Energy efficiency shall abide to MS1525:2007 standard	Shall utilise natural lighting through air-well, opening and air-vent	NRNC EE: 35% of GBI guideline encompassing energy efficiency through exploiting available green certified lighting and lower OTTV	N/A
Socio-Cultural	Not specifically mentioned in regulation, but, UBBL has emphasis UD and public space requirement in shop houses	Shall conduct Cultural Impact Assessment (CIA) to take urban context coherent with the building including physical landscape, economy and community aspect	Township CPD: Encompassing diversity in community and mix land use by providing secure design, health and basic amenities	N/A

Urban development	N/A	Assessing the impact of cultural diversity, living heritage and townscape in CIA. Encouraging mix use in land development in promoting urban interaction	NRNC SM: Integrate community with greater compact density with promoting green transportation. Under SM3 provision to provide basic amenities in the surrounding.	Greater emphasis to car park spaces to facilitate contemporary needs either concentrated or incorporated into building space

5. DISCUSSION AND RECOMMENDATION

The analysis of the studied policies has provided critical in-sight into contemporary practices. The cross examination between policies has provided fundamental knowledge into this proposed framework (Table 2). The framework comprises of 3 factors namely; Building Envelope Design (BED), Green Design (GD) and Cultural Design (CD) to determine fundamental values that should be embedded into future developments based on analytical research presented in Table 1. New technology and innovation in GD should be encouraged to enhance the building performances and fulfil the green agenda. Yet, passive design should always be prioritised to avoid ill-practises in this framework. Nonetheless, further research from public survey, climatic factor and physical simulation (Edwards & Naboni, 2013) is needed to testify the framework viability.

Green-Shop Framework

Item	Description	Remarks
Building Envelope Design (BED)		
BED1: Building Physical	1) Shop house shall not build higher than 5 storey or 18 meters. 2) Shop house shall maintain higher ceiling height with minimal 12 ft. ht. to assist passive ventilation. 3) Shop house shall maintain 20 ft. or more width and more than 70ft. depth	1) Exceeding 5 storeys shop house is not supporting socio-economy with difficult accessibility. 2) Higher ceiling height allows stack ventilation and cross ventilation. 3) Deeper and wider shop house provides greater usable space with better air quality per occupant.
BED2: Façade Treatment	1) Shop house with East-West façade orientation shall have thicker wall insulation compared to North-South orientated façade.	1) Studied recorded East-West orientated buildings have greater heat gain by 20-30%, hence, required thicker wall insulation or shading devices.
BED3: Five Foot Way (Verandah-way) and Accessibility	1) Verandah-way shall not be obstructed by any means to ease pedestrian use. 2) UD shall apply to shop house design for all user accessibility. 3) Concentrated parking space or using basement as car park space could maximise land use and allow pedestrian-prioritised scheme on street level	1) Comprising SAP and UBBL guideline to provide comfortable pedestrian friendly network. 2) UD is required for disable accessibility. 3) Pedestrian scheme could enhance socio-economy with more space for community activities and engagement. While, concentrated car park space would provide safer zone for pedestrian use.
BED4: Air-well and Rear Court	1) Restricted physical space, air-well would not be suitable for contemporary shop house design. Alternative solution such as skylight or light shaft could be employed. 2) Rear court shall be maintained for hygiene and optimising back lane functionality.	1) - 2) Rear court space could be used for green space and allow greater ventilation. Back house activities could be contained within building, hence, promoting cleaner communal space.
BED5: Staircase Access	1) Enclosed staircase practice could be designed as light-well for shop's interior. 2) Staircase is encouraged to have more opening for ventilation and admitting daylights	1) As interconnect space, staircase is suitable as a daylight source for internal spaces. 2) -
Green Design (GD)		
GD1: Building Material	1) All building materials shall abide to fire safety use and endorsed by local standards. Green certified materials should be prioritised. 2) Materials shall not be restrict but would be encouraged to use local products with consideration of urban coherence.	1) - 2) Using local products could reduce transportation's carbon footprints. Meanwhile, building materials could disturb urban coherence with unnecessary adornment.
GD2: Energy Efficiency	1) Shop house shall be designed to maximised day lighting to reduce dependency of artificial lights. i.e. light shelf, light-well, light shaft 2) Users are encouraged to use green certified products as suggested in GBI guideline.	1) - 2) -
GD3: Passive Design	1) Shop house shall optimise passive design (i.e. orientation, insulation, ventilation) and reduce mechanical assistance whenever possible.	1) Research show local occupants have higher tolerance for regional climate. (Omar & S.F.Syed-Fadzil, 2011)

GD4: Indoor Air Quality (IAQ)	1) Passive ventilation should be prioritised through encouraging air-vent design, more opening space and jack roof design. 2) Mechanical ventilation shall not be part of alternative building design. Mechanical ventilation shall only be applicable to encourage air flow	1) Studied recorded passive ventilation is sufficient to provide effective ventilation in shop house building. (Omar & S.F.Syed-Fadzil, 2011) 2) Mechanical ventilation could be adopted to remove pollutants. Mechanical fan and attic fan could be adopted to encourage stack ventilation or cross ventilation in the building
GD5: Thermal Comfort	1) Thicker insulation for wall and roofing to reduce heat gain. Shading devices (i.e overhang, louvres) should be employed. Shop house shall refrain from using tinted window 2) Shop house shall have greater thermal mass to reduce u-value on strategic part of the building (i.e East-West orientated wall/facade)	1) Thermal resistance shall increase to lower internal temperature, while, reducing solar heat gain with strategic employment of shading devices. 2) Shop house shall meet 0.4 W/m2K (u-value) requirements regardless of building size.
GD6: Technology and Innovation	1) Green high technology and innovation are encouraged in accordance to advancing society. 2) New technology application shall adhere to local green standards.	1) High technology shall not replace or supersede passive design whenever possible. 2) Technology adoption shall be thoroughly studied before application to avoid ill practices.
Cultural Design (CD)		
CD1:Cultural and Community	1) Developer shall conduct post-occupancy evaluation (POE) to understand regional (local) communities in Malaysia. 2) Shop house design shall be inspired by local design to reflect the rich cultural differences	1) POE could empower architects engagement with end-users to understand local community's culture, place attachment and reduce unnecessary features or adornment 2) Place identity is important for new development in searching of sense of belonging and attachment.
CD2: Socio-Economy	1) Shop house development shall asses economy value to provide basic amenities for residential area	1) Basic amenities and local working opportunity shall undergo studies to reduce unnecessary shop house development at mature neighbourhood
CD3: Urban Context and Identity	1) Mix land use development shall be maintained and integrated with local communities. 2) Shop house development shall consider all basic facilities to attract local community engagement	1) - 2) -

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Session 3B : Innovative technologies

PLEA2014: Day 1, Tuesday, December 16
16:05 - 17:45, Compassion - Knowledge Consortium of Gujarat

TOWARD AN INNOVATIVE TEMPORARY EVENT STRUCTURE BASED ON BIOCLIMATIC PRINCIPLES

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ABSTRACT

In the context of temporary events, the use of structural systems suitable for short-term use is a key strategy in terms of organization. However, this type of ephemeral structure currently requires the implementation of significant resources, for which the characteristics of flexibility and economic efficiency most often prevail over considerations related to sustainability.

This lack of sustainability exists due to several attributes of a temporary building. Firstly, the distance between the place of storage and the one of use requires transportation, which can sometimes represent a significant share of consumption and environmental impacts. Furthermore, heat energy required to achieve an acceptable level of indoor comfort in a building with little or no thermal isolation is disproportionate to the short time of use. Finally, the materials used, in most cases, have a significant life cycle in terms of embodied energy required for their manufacture and respectively their disposal. However, many parameters are not as yet subject to specific studies. Contributing to remedy this lack, the present paper aims to evaluate the environmental impacts and lack of performances of current temporary event structures. In order to compare them with the expected performances of an alternative proposition –the On STAGE Project-, which refers to architectural quality and high level of comfort with an optimal use of resources and a minimization of environmental impacts.

Firstly, a detailed analysis of a typical ephemeral structure system is presented, through an assessment process, that takes into account not only environmental criteria calculated on the whole life cycle, Non Renewable Energy (NRE) and Global Warming Potential (GWP), but also the thermal and acoustic comfort. Then the set of results will be compared to the simulated values for On STAGE Project, and show that it is possible, through an integrated design process based on the principles of bioclimatic architecture and the use of renewable energy sources, to design a temporary structure capable of high level of comfort, preserving resources and reducing environmental impacts, in order to meet sustainability goals, even in the case of a short lifespan.

INTRODUCTION

In consideration of the especially significant number of cultural manifestations (festivals, shows, exhibitions, commercial, trade fairs, fairs, exchanges), sportive or political festivals, where the assembly of temporary structures is necessary, a tangible need regarding the material is manifested. Nevertheless, the consultation of all regional, national or international agendas, which appear on the media, induces an impression of the real growth in the event branch. The specific analysis, as measured by a country like Switzerland, shows this importance: the revenues generated by the event industry have increased regularly since 2003 by 6% per year (DESILVA, 2008). Furthermore, it is noted that the International Organization for Standardization (ISO) has published a new standard for organizers of events in order to increase integration of sustainability into their activities (ISO, 2012). This standard emphasizes in particular the need for certain temporary event constructions, thus avoiding oversized infrastructures in relation to actual needs once the event happened.

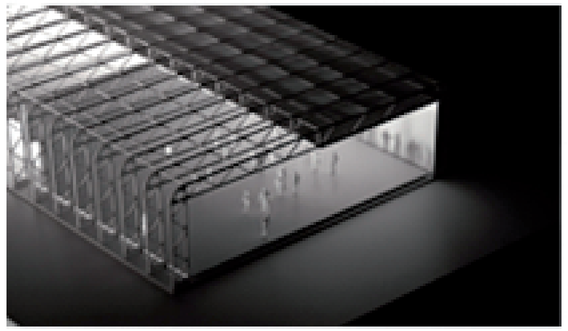
These figures highlight the interest in the planification of a sustainable alternative, which is characterized by a strong development potential, and therefore which should be designed in a sustainable way. Not only in terms of flexibility and speed of erection but also in term of inner comfort, thermal and acoustic performances, from architectural aesthetics point of view, or regarding gray energy needed for manufacture, use and transport and their environmental impacts. To do so this article observes, through a multi criteria evaluation of sustainability parameters, a typical structure system, representative of current practice. An useful assessment in order and set out the specific objectives for planning an alternative: the "OnSTAGE project" and compare it to the current practice. The “OnSTAGE project” is currently under development through a process of integrated design, that will provide a reliable base for the realization of an operational prototype by optimizing iteratively different dimensions of the project (APPLEBY 2011).

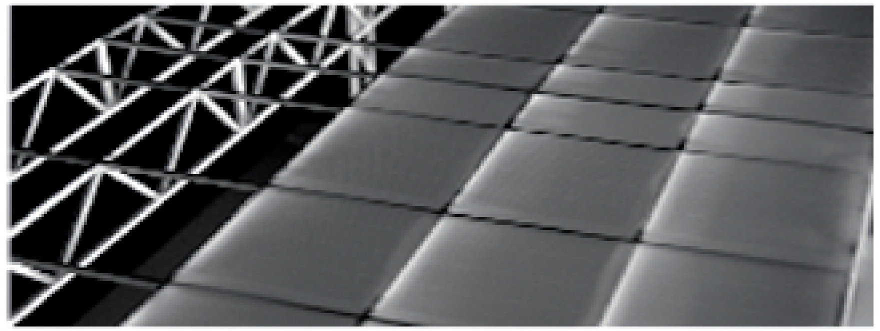
LIMITS OF THE COMMON PRACTICE

In order to comprehend more precisely the advantages and the disadvantages of the usual practice, a case study has been conducted on a representative model of this kind of temporary structure. A tent of classical fabrication had been specifically chosen, which harboured the main stage at the Cully Jazz Festival (Switzerland), destined for about 1000 viewers. This case study took place in April 2011. The results of these analyses are summarized below.

Thermal comfort

To assess the climate inside more precisely, four data loggers had been place inside and outside the tent during this one-week festival. The results clearly highlight typical characteristics of light construction. The fact that the tent hasn't any insulation or thermal sealing, made it very susceptible for the different temperatures outside, but especially for the influences of the direct solar radiation. Indeed the important variation of the monitored temperatures, at the beginning of the afternoon, on a sunny day and on a very cloudy day expresses the strong dependence of the inner climate on the direct solar radiation. A second peak in inner temperature had been registered at the end of the evening of the concert. The presence of one thousand viewers represents a huge energy input inside and may not be neglected and it is recommended to consider the users (viewers, musicians and technicians) in the objective for the improvement of the thermal comfort. These two major factors influencing the climate inside, which are the direct solar radiation and the internal heat gains, are furthermore not controllable by the operators. In case of the analyzed construction it remains difficult to compensate the climatic variations inside and however reach satisfactory thermal comfort (LAST et al. 2011).





Acoustic comfort

The acoustic comfort and emissions sound to the neighborhood is also influenced by the light construction. To evaluate the acoustic quality inside, the times of reverberation had been measured during a concert. The results indicate that it is possible to stay within the optimum area for jazz, but with one time measuring around the limits for the bass frequencies as a consequence of the light construction of the model. An optimisation of the model with big awnings made of cloth tensed across the ceiling of the tent, contributes to improve the periods of reverberation in order to reach a satisfactory level for the jazz. (LAST et al., 2011). During the analysis, a noise pollution had been detected in case of strong wind, resulting from the movement of the construction and the ceilings. This annoying noise is the result of the fact that cloth skin is not put under tension and therefore can float in the wind. This kind of repetitive noises can be really disturbant for spectators and musicians, especially when the sound volume of the concert is low. One last aspect is concerning the sound emissions outwards and inwards, that are very important and generate significant noise coming from inside for the neighborhood and coming from outside for spectators. However measured values on different positions in the neighbourhood are far above the legal limits. Even if this type of ephemeral use often benefits from a certain tolerance on the part of the neighborhood, a level that is so high reduces possibilities of implementation on certain sites (LAST et al. 2011).

Consumption of non-renewable energy (NRE) and environmental impacts (GWP)

Another aspect that is revealed by the assessment of current practice limits considering criteria of sustainability is the environmental impact of materials choices. Indeed the necessary grey-energy isn't subject to special verifications, especially regarding the influences on the environment. For example in this case study, aluminium is the main material used for the structure, as it offers interesting characteristics of lightness and hardiness, but it although requests a lot of energy during its production. As illustrate on figure 4, it represent until 63% of non-renewable energy (NRE) and 51% of global warming potential (GWP). In this way a better planning regarding the material use could optimize this aspect. Another environmental impact revealed by this assessment is the huge energy consumption required to heating system. To reach an acceptable inner climate during cooler periods, it is necessary to compensate the thermal losses of the casing of the tent by using temporary heating oil devices, whom energy is quickly dispersed due to the light construction (FUMEAUX and REY 2012)

TARGETED OBJECTIVES FOR THE "ONSTAGE PROJECT"

Regarding the analysis and the significant points mentioned above, the following targeted objectives are formulated:

1. Flexibility is the first objective. The project has to be able to offer adequate advantages for the current practice. Constructive modalities by elements offer an important level of modularity in term of size and comfort of the structure.
2. Comfort optimization of the planned structure must permit the users the optimal management of the thermal and acoustic comfort. The objective is to keep the inner climate in a comfortable zone, which is the same condition as outside and the occupancy rate (ROULET 2010).
3. For an optimal use of resources the project will include architectural bioclimatic principles, especially regarding the thermal insulation, protection from the sun, natural ventilation and passive refection, which allow the reduction of its energetic demand (warmth and cold) and the prior valorisation of resources that are locally disposable (AIULFI and REY 2010)
4. The project aims at establishing a basis of a concept of efficient economic exploitation of the structure. By rationalizing the process, the project has to reach an economic feasibility for the operator. The project aims at establishing bases of a financially balanced concept, regarding its lifecycle including an optimization of production costs and exploitation (REY and RYTER 2003)
5. The concept and the realization of the new infrastructure, likewise temporary and permanent, will include a special care for the architectural expression. The system will be well conceived in a way that it will contribute to the expression of a spatial coherence and offer a harmonic integration of the object in the different contexts where it will finally take place.

FROM A CONCEPTUAL VISION TO AN OPERATIONAL PROTOTYPE

Subsequent to the definition of the objectives of the project, a conceptual vision has been developed in order to set the basis of the constructive system and to specify the components that have to be developed in detail regarding the specific objectives mentioned. This conceptual vision is the basis of integrated design in the course of which the interdisciplinary competences of the different partners of the project (civil engineers, experts for thermal and acoustic, carpenters, specialists for photovoltaic and operators) have to optimize the conceptual vision.

Bioclimatic strategies and reduction of energy demand

The scheme of figure 1 shows the planned principle for the management of overheating situation at daytime. To avoid overheating, the conceptual vision includes architectural bioclimatic principles. A passive strategy which is based on the given space between the two layers of the casing, which is used as a sealed space that helps to deflect warm air by providing a tempered layer, which contributes to the thermal insulation for inside temperature's stability even in cooler periods. After reducing the needs of energy through bioclimatics strategies, the project implements a concept of comfort ventilation with heat recovery, coupled to a battery (hot-cold) powered by an air heat pump. A device tested in the field of sustainable buildings, but which apperars as a pionner experience in the field of temporary constructions. Finally, photovoltaic panels integrated into the roof structure (rigid / flexible technologies) provide renewable source of electricity.

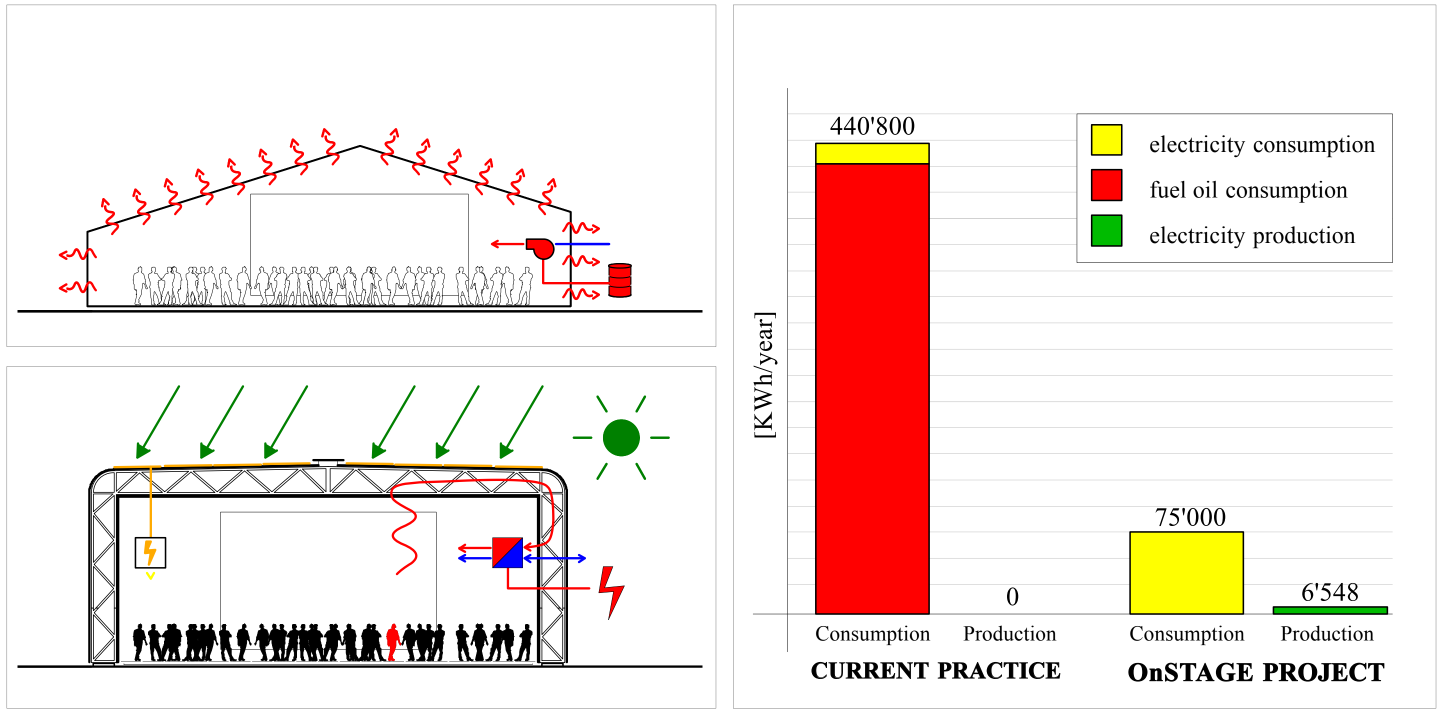


Figure 1 Comparison of energy consumed and produced (final energy) for annual use (100 days per year) for the conventional device and the project "On STAGE".

Inner acoustic quality and noise transmission

Regarding the acoustic and as illustrates on figure 2, the additional mass that is filled inside the acoustic panels will help to control the acoustic of the room better, especially in term of low frequencies. The double side acoustic panels (smooth and absorbent) avoid flexible inside skin configuration for an optimal acoustic diffusion according to size and need of use. For the reduction of the noise toward outside and inside the project proposes to add an acoustic skin of 10 kilograms per square meters to reduce sound emissions towards the envelopp up to 25 dB. It may therefore benefit from a certain tolerance from the neighbourhood, and increase opportunities for implementation on most sites.

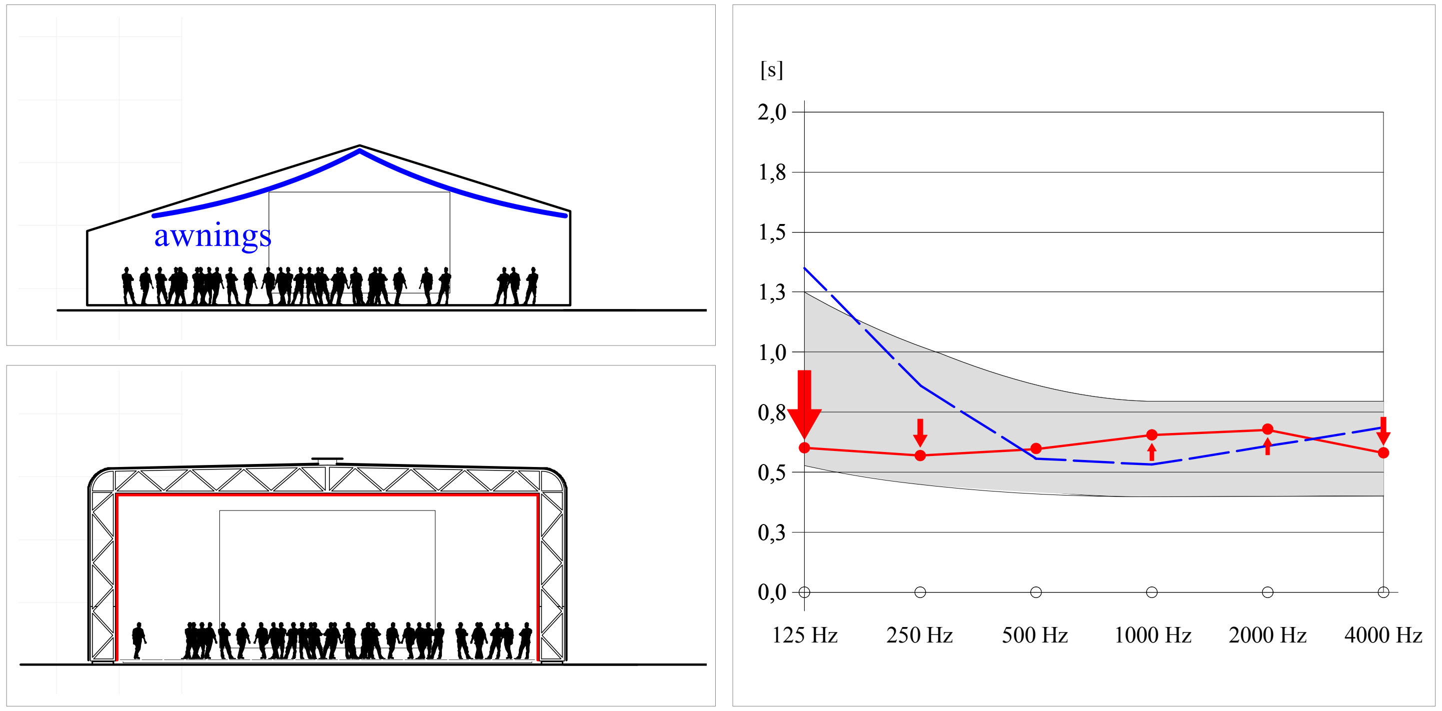


Figure 2 Comparison between current practice and the project "OnSTAGE". The additional mass that is filled inside the acoustic panels will help to control the acoustic of the room better. The double side (smooth and absorbent) acoustic panels allow the flexibility to optimise the acoustic quality of the concert hall.

Reduction of non-renewable energy and environmental impacts

Along with these measures at the operating energy demonstration project "On STAGE" is also characterized by a significant reduction in embodied energy and emissions of carbon dioxide. A guidance and estimated the graph shown in Figure 7 shows a comparison of the overall balance in terms of non-renewable primary energy (NRE), and CO2 equivalent emissions (GWP). Reduction between the conventional system and the demonstration project "On STAGE" is of the order of 60% for primary non-renewable energy (NRE) and 40 % for CO2 equivalent emissions (GWP) (FUMEAUX and REY 2012).

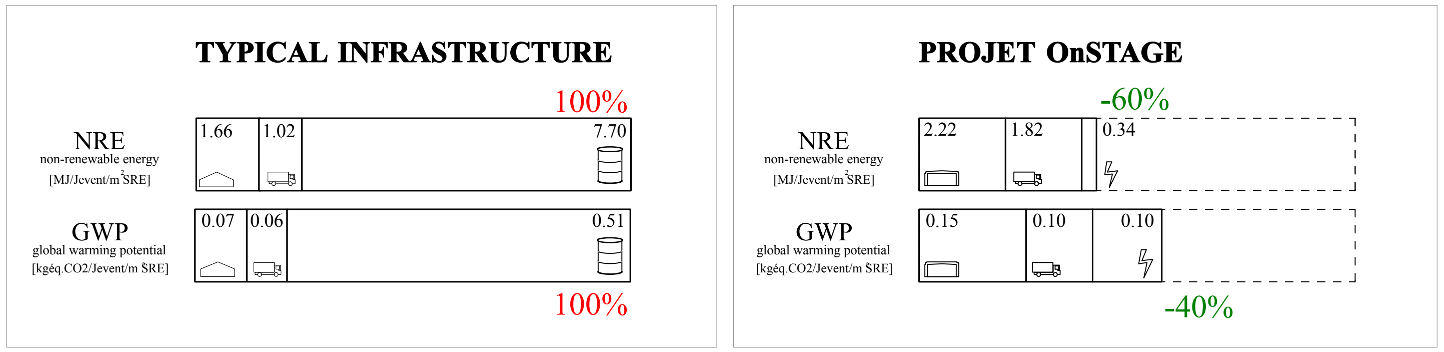
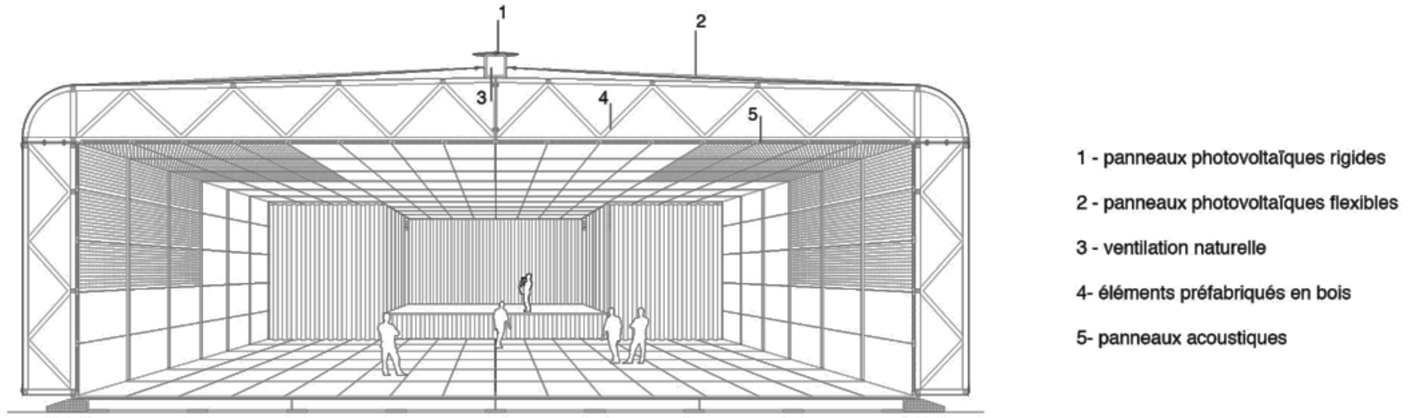


Figure 3 Comparing the estimated overall record non-renewable primary energy terms (NRE) and CO2 equivalent emissions (GWP) for the conventional device and the project "On STAGE".

CONSTRUCTIVE APPROACH

As shown in figure 4 below, the structure is composed triangulated frames, compounds of wooden elements, prefabricated in factory and assembled on site (ERNE Holzbau AG et al., 2013). On this structure are fixed, an inner casing of wooden panels and an outer casing made of PVC membrane. The modularity of the project is based on a small number of pieces, which can be combined for different sizes with variables of quality level. The project "On STAGE" so offers a dual flexibility.



PROSPECTS

Following this integrated design process it is possible to dispose of an operational prototype, for which feasibility is verified and demonstrated. The next phase of the project is to go deep each element imagined conceptual and technical level to achieve complete constructive study, to establish prefabrication plans and finally to build the structure. With these complementary steps, this integrated design process will lead to the realization of the first sustainable alternative for ephemeral event structures.

In the field of event-structures and linked profesionnal constructors, the project appears as a breakthrough achievement that offers a real alternative to the current practice. By the way, such a realization has some interest and should thus contribute to the evolution of common practices. The project "On STAGE" will have also impact the general public and the awareness of energy issues. Indeed, the project will be the main area of concerts for the next editions of Cully Jazz Festival, an annual event that hold on a history of over thirty years, on an established international reputation and on a public of about 50,000 visitors per edition. The project "On STAGE" and the results obtained in terms of reduction of environmental impacts will be integrated into the future communication strategy of the festival.

ACKNOWLEDGMENTS

Initiated by the Laboratory of architecture and sustainable technologies (LAST), the creation of the project "On STAGE" is the fruit of cooperation between many partners that we want to thank hereby for their support and their participation. Our appreciation is also particularly addressed to the Interdisciplinary Laboratory of Performance-Integrated Design (LIPID) at the EPFL in Lausanne, to the Cully Jazz Festival and to the companies ERNE AG Holzbau in Laufenburg, GVH SA à St-Blaise, A 21 Sàrl in Neuchâtel, Thorsen Sàrl in Echandens and Sorane SA in Ecublens.

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Sustainable habitat: market trends and testing of innovation products

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ABSTRACT

Sustainable development is recognised as a particular challenge, with the need to reduce costs and increase efficiency. In this contest there is continued interest in determining how to enhance innovation in the construction industry, since innovation is vital to successful, long-term company performance in the construction industry. But what is the role of the innovation for systems and components in the future? Will we be able to change the existent technological systems and to develop innovative products in order to influence the building market or create really new ideas capable of change to the life style of the people?

The objective is achieve a sustainable good quality construction as a continue process starting from the new characteristics and new opportunities for the enterprises and develop new components with high efficiency in order to satisfy the construction market and to meet the demand for high-performance by the users. To achieve this, a close relationship between research world and manufacturing companies play a key role, especially in the development phase of new performing products and for the improvement of new architectural solutions studied for their integrability in the buildings. A market trend, create by new business inquires, develop a greater attention on energetic and environmental issues.

INTRODUCTION

Several key factors influence the evolution of building energy consumption and emissions, including population growth, which increases demand for residential buildings and services. Building sector energy consumption grew 18% between 2000 and 2010, to reach 117 EJ – around one-third of global final energy use, producing about one-sixth of end-use direct CO2 emissions. So the buildings are responsible for the largest share of energy consumption and associated greenhouse gas (CO_2) emissions.

The challenge of the future efforts of the construction sector should be properly addressed by policies in order to mobilize the market towards a low carbon society and trigger multiple benefits (such as the independence from energy imports from politically unstable areas, job creation, improved air quality and indoor comfort, reduced fuel poverty etc.).

Near-zero energy consumption in new – and existing – buildings and communities is possible. Designing a carefully chosen research and development strategy will enable the building industries to move from incremental – to substantial – energy savings and reductions in greenhouse gas emissions. The aim of the implementing agreement for a programme of research and development on energy in buildings is to take advantage of energy-saving opportunities to remove technical obstacles to market penetration of new energy conservation technologies for community systems and residential, commercial, and office buildings. To implement this strategy, research activities have to focus on dissemination, decision-making and building systems. When buildings are constructed or renovated, a whole-building perspective is preferred, which involves considering all parts of the building and the construction process to reveal opportunities to improve energy efficiency. Numerous whole-building perspectives and policy mechanisms exist, such as building performance certificates and whole-building labelling programmes.

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In these perspectives, detail the building envelope's impact on energy consumption should not be underestimated. While whole-building approaches are ideal, every day building envelope components are upgraded or replaced using technologies that are often less efficient than the best options that will be available if we invest in the innovation. These advanced options, which are the primary focus of the future in the construction, are needed not only to support whole-building approaches but also to improve the energy efficiency of individual components:

- high levels of insulation in walls, roofs and floors, to reduce heat losses in cold climates, optimised through life-cycle cost (LCC) assessment;
- high-performance windows, with low thermal transmittance for the entire assembly (including frames and edge seals) and climate-appropriate solar heat gain coefficients;
- highly reflective surfaces in hot climates, including both white and "cool-coloured" roofs and walls, with glare minimized;
- properly sealed structures to ensure low air infiltration rates, with controlled ventilation for fresh air;
- minimisation of thermal bridges (components that easily conduct heat), such as high thermal conductive fasteners and structural members, while managing moisture concerns within integrated building components and materials.

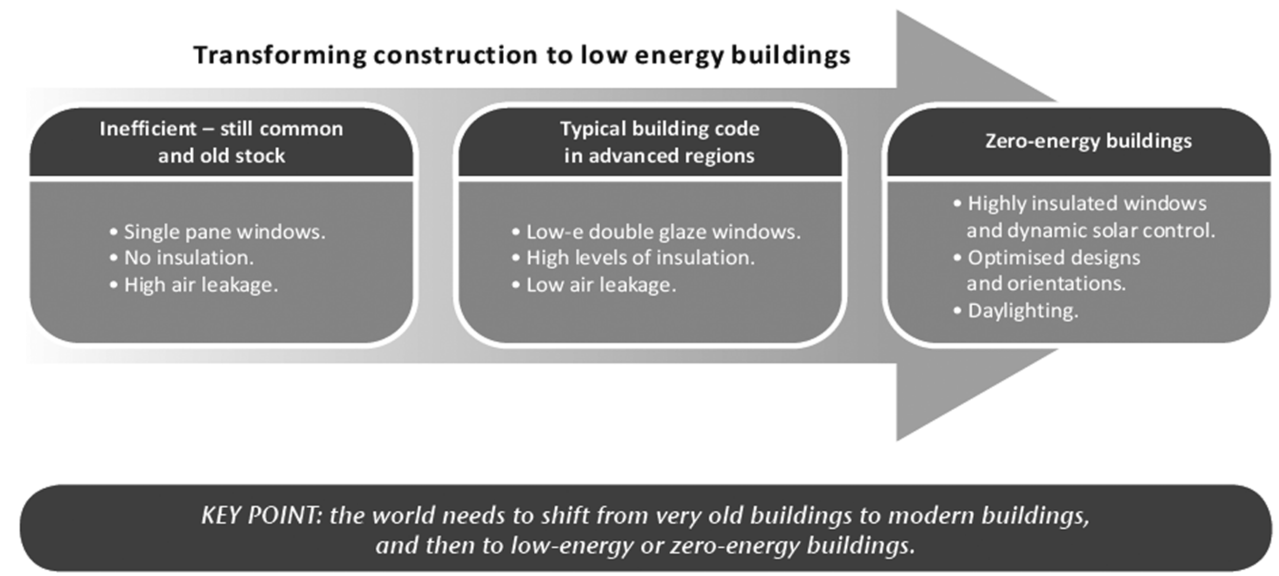

Figure 1 Progression construction of building envelopes from old stock to future technology. (Source: IEA Report Technology Roadmap Energy efficient building envelopes)

Analysis of building envelopes is complicated by the extreme global diversity of building materials, climates, and standards and practices of building design and construction, but it is vital to ensure for new and retrofit buildings, the use of the most efficient technologies. So, the suitability of energy-efficient technologies depends on the type of economy, climate and whether the materials are being used for new buildings or retrofits. To achieve the large energy savings that efficient building envelopes can offer, full market saturation of high-priority, energy-efficient building materials is essential. Not only but is more important to invest in RD&D on the following technologies that will lead to greater returns on investment:

- highly insulated windows
- advanced, high-performance, "thin" insulation
- less labour-intensive air sealing, and lower-cost validation testing
- lower-cost automated dynamic shading and glazings
- more durable and lower-cost reflective roof materials and reflective coatings.

Cost is a primary barrier to greater application and in some cases there are also concerns about long-term performance. There also is a lack of knowledge about innovative applications, and detailed design guidelines are limited. Greater effort is needed to highlight applications that are viable in market terms, such as locations in buildings with space limitations that will usually require a combination of high thermal performance insulation with lower material cost. Also, a systems perspective can allow for high-performance insulations to reduce labour costs, especially for building renovations (e.g. interior wall insulation in historic buildings), so cost-effectiveness does not have to be limited just to the material cost of a system.

INTENT AND OBJECTIVES OF APPLIED RESEARCH WORK

What is the role of the innovation for systems and components in the future? Will we be able to change the existent technological systems and to develop innovative products in order to influence the building market or create really new ideas capable of change to the life style of the people? The answer to this questions is achieve a sustainable good quality construction as a continue process starting from the new characteristics and new opportunities for the enterprises and develop new components with high efficiency in order to satisfy the construction market and to meet the demand for high-performance by the users. Market barriers preventing the adoption of energy-efficient buildings or building materials can be real or perceived. As well as simple failures such as a lack of knowledge about alternative options, they can include concerns about the performance, expected energy savings, reliability and service life of a new product. Some new construction materials and approaches oblige builders to completely change the way a building is erected.

Barriers in emerging markets can include import tariffs, a lack of product performance metrics and a lack of installation procedures. In many countries there are also institutional barriers such as lack of government oversight or interest, lack of appropriate market signals to promote efficiency, and lack of basic infrastructure. To deploy energy-efficient buildings, several institutional and market barriers need to be overcome. The following core elements should serve as good starting points for policy makers in regions where construction practices do not typically include energy-efficiency strategies:

there is a large array of technical requirements to enable the installation of more efficient building envelopes. These include proper test performance metrics and associated testing equipment so that third-party test ratings, certificates and labels can be established. Skilled labour is essential to conduct tests, assess alternative building solutions, promote efficient building policy, install new materials, conduct inspections and ensure compliance. It is also vital to make available general education materials such as guidelines adapted for the specific markets; energy calculators based on local climate, energy prices and occupant behavior; and an overall improved knowledge base of more efficient options.

while demonstration buildings can be built with materials imported from distant places, for energy-efficient buildings to become viable the materials need to be manufactured much closer to the construction region, since shipping costs for large, heavy materials can be prohibitively high.

to ensure that factories are built that can produce commodity materials on a large scale, governments need to give clear signals about their interest in promoting efficient building envelopes, and often other support such as market-based or higher energy prices (higher tariffs). Policy makers need to have an open dialogue with the building material industry about key elements that will help drive investment. Manufacturing building materials domestically, or at least regionally, creates jobs not only in local manufacturing but also for global investors involved in specialised tooling and unique raw materials.

In this contest, in Italy, to overcome these barriers and stimulated by the scenarios provided by the European Community, the regional administration of Tuscany, has funded a research project "Abitare Mediterraneo" (www.abitaremediterraneo.eu) aimed to develop synergy between industrial companies, builders and research centres, to increase competitiveness in building sector and meet European and National standard requirements. The project aimed to increase the energy saving in Mediterranean climate, focusing on summer comfort, developing and testing innovative solutions with national and EU companies. The research has developed advanced tools, as a Database, a Test Cell, and a new Spin-off on sustainable architecture and innovative products.

APPROACH AND OUTCOMES

The catalog of meta-design solutions "Abitare Mediterraneo" analyzes performance requirements of specifics of building innovative components for Mediterranean climate. This library is a reference point for designers that approaching not only at energetic projects but also at projects were, new pattern of space, contribute at indoor comfort. The database want create a map of the building system were technical and innovative typological solution are connoted by the requirements of space and performance of solution. Inside the database it's possible choose, within a large group of products for building, components and technological systems (new and existent) more efficient to energy saving: the user can develop meta-design solutions in terms of performance and in relation to environmental characteristics of Mediterranean areas. For every solution is possible identify the most important requirements and some meta-design indications, connected with the technical solution database where it is possible to found different solution for answer at requirements indicated.

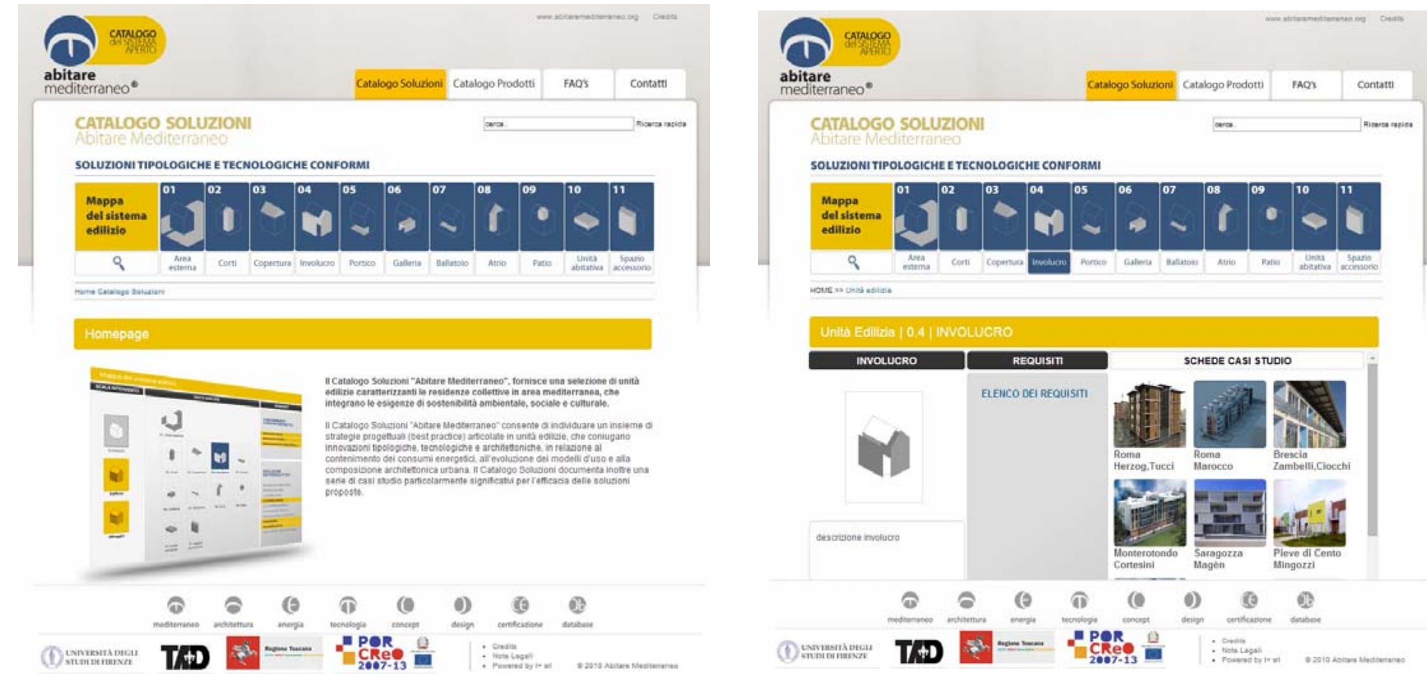

Figure 1 The database web screen with Database structure (Source: www.abitaremediterraneo.eu)

This database structure have developed a system to surfing inside a specific meta-design, technical and performance solutions of building and envelop in relationship with the energy legislation. Moreover, the multimedia library create a complete tool to help designers, companies and public administrations to design building in Mediterranean climate.

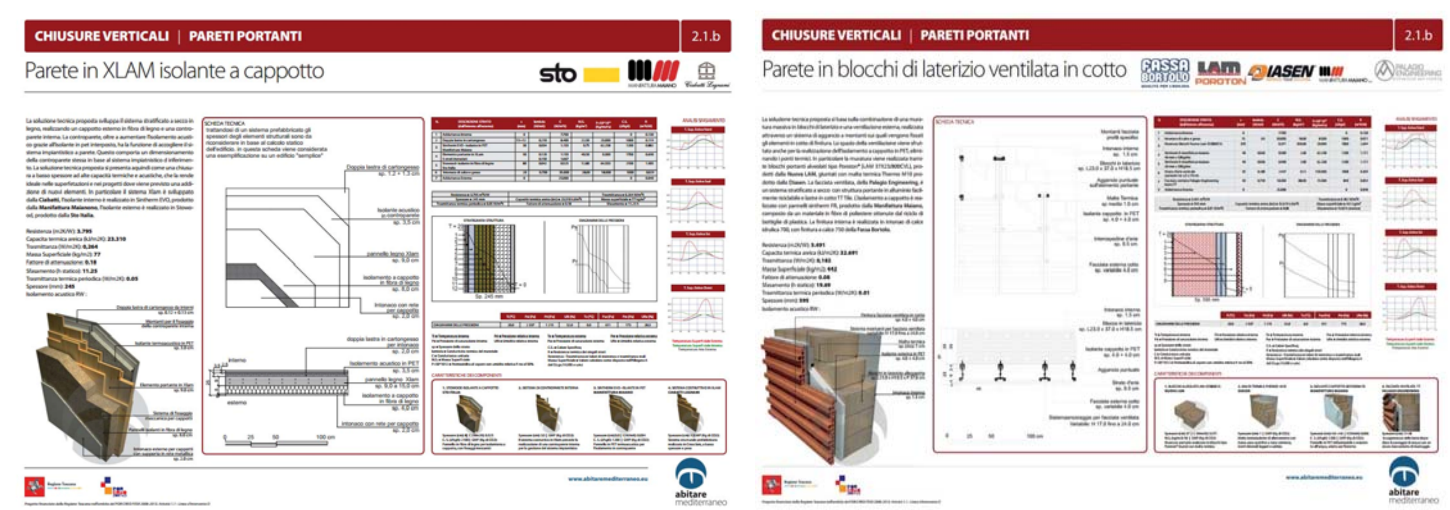

Figure 2 The database web screen with the products and the specific performance that characterize them (Source: www.abitaremediterraneo.eu)

At the moment the research group have not yet carried out any checks on how this tool has been used until now. The next step will requires a careful analysis to verify, through a dedicated monitoring system for the evaluation of the results and thus validate the effectiveness of this tool.

Another important result of Abitare Mediterraneo research, was been the construction of an outdoor Test Cell to assess the dynamic thermal behavior of building surfaces; an instrument for giving the opportunity principally to local building market to test new products that needs to be used in Mediterranean Climate, products that are able to reduce annual energy consumption in buildings working with a sufficient insulation level and appropriate thermal inertia if necessary. In fact, with this tool, can be run tests on innovative exterior wall elements, in exterior ambient conditions and the data that can be obtained, include thermal damping factor, delays, solar aperture factor and U value. The test cell features instruments for multi-channel monitoring a weather station and their own analysis software. Outdoor test cells, where there is a high degree of control of the indoor environment, well-specified constructions and high levels of instrumentation, can certainly fill the gap between laboratory testing and full-scale building testing. In fact the main use of testing in outdoor test cells is the link with simulation modelling.

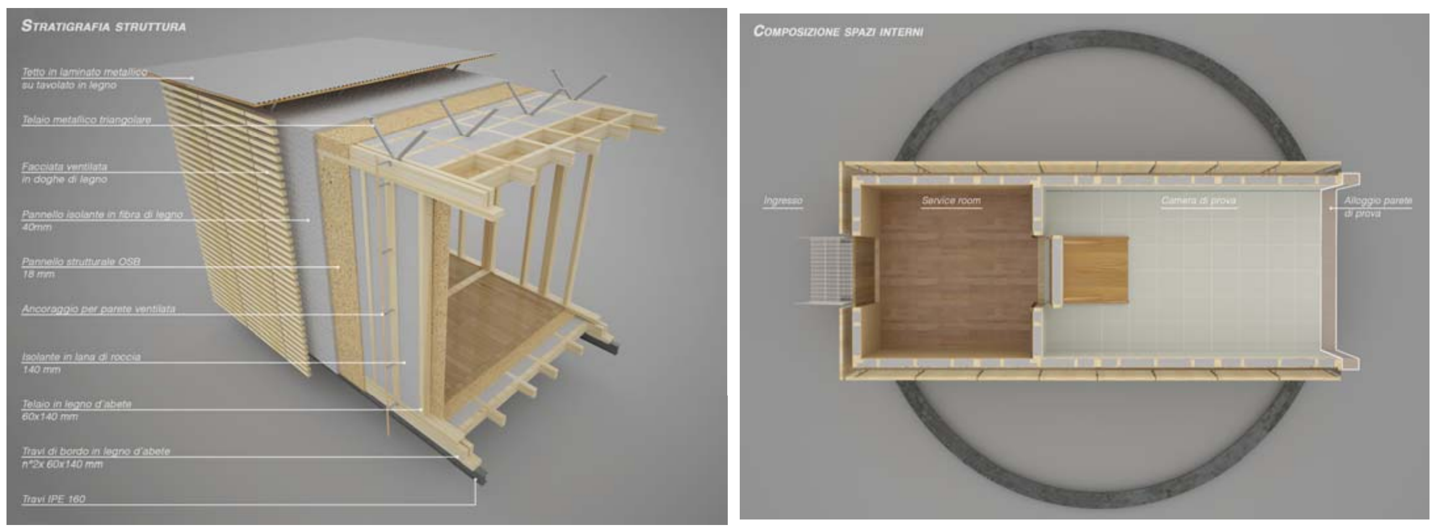

Figure 3 The structural and technological project of outdoor Test Cell realised in Italy (Florence) within the Abitare Mediterraneo project. (Source: www.abitaremediterraneo.eu)

The innovative perspective is that dynamic simulation programs have improved in capability and validity and can therefore be used with some confidence in predicting energy and environmental performance of buildings. However, where a new component is under development, for example an advanced glazing, a hybrid photovoltaic module or shading component, then high quality datasets from outdoor experiments can be used to ensure that the simulation program is capable of modelling that component. If so, it is considered that the simulation program can then be used to model the component when integrated into a full-scale building.

Basically the principal mission of this research programme was been develop and facilitate the integration of new technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. So the outdoor test cell realized in Italy within the Abitare Mediterraneo project, is a point of reference for companies and manufacturers of innovative components; a technology lab with an extensive program of service and open to all producers who wish to verify the performance of new products for the building to be placed on the market to promote energy conservation and sustainability in construction.

Figure 3 The outdoor Test Cell located in Italy (Florence) in the University Campus (Source: www.abitaremediterraneo.eu)

CONCLUSION

Innovation within a project, company and occupational industry provides the opportunity to realize significant benefits and, in a competitive market, is a requirement for continued existence. All companies must innovate at some level in order to stay competitive. Innovation in the construction industry may take place at a lower rate compared to other industries due to the structure and characteristics of the industry and projects, but it does, and must, occur in a competitive market.

Product innovation is an important activity in corporate entrepreneurship and technology management. The successful introduction of new products into the market is a critical factor for the survival and growth of companies. However, the increasingly dynamic and turbulent environment in which firms compete makes the commercialization of a new product not only a necessary, but also a risky venture.

Anyway, to unleash the full potential of energy savings related to buildings, the additional value of improved energy efficiency (e.g. improved indoor climate, reduced energy cost, improved property value, etc.) must be recognised, and the lifetime costs of buildings have to be considered rather than just focusing on investment costs. Over the last decade, building policies in the European Union increased in their scope and coverage and are moving towards an integrated approach taking into account the energy, environmental, financial and comfort related aspects.

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Design Strategies on Heat Recovery of Cooking Stove in Rural Houses of China

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ABSTRACT

Wulong County is a high altitude mountainous region located in the southeast of Chongqing Province, included in the hot summer and cold winter (HSCW) climate zone of China. The indoor and outdoor temperatures are quite low during the winter and sometimes are intolerant for local occupants. The percentage of possible sunshine is only 13% in winter according to meteorological data, which makes it nearly impossible to use solar energy for space heating. Other ways of heat gaining without extra energy consumption should be explored for the rural houses of this area. This paper analyzed impacts of cooking activities on indoor environmental quality, and estimated the potential of heat recovery of cooking stove for space heating. We conducted in-depth observations of occupants' behavior (including life patterns and cooking activities) and field investigations on thermal environment and indoor air quality. A series of design strategies were proposed based on these survey results. The strategies emphasized the utilization of heated walls and a proper room layout.

INTRODUCTION

The hot summer and cold winter (HSCW) climate zone, with 0.55 billion people living there, covers a grand area of the central China. The climate is far harsher than any other places of the same latitude. Wulong County located in Chongqing Province with an average altitude of over 1, 000 meters above sea level, is a representative area of the HSCW zone. The annual average temperature is 15-18°C. The extreme minimum temperature can reach as low as -3.5°C，while the highest temperature is 41.7°C, with high humidity all year round. The annual precipitation is 1000-1200mm. Most precipitation is April to June for four months, accounting for 39% of annual precipitation. People live in this remote mountainous area suffer from both extreme hot summer and cold, wet winter. The present existing rural houses fail to achieve thermal comfort especially in winter. According to the field measurements performed in February, 2012, the average indoor air temperature of a traditional timberwork house is 2.45°C. The indoor temperature even falls below zero sometimes. The situation with the modern concrete house is no better. The average indoor air temperature is 4.59°C with the minimum value of 1.4°C, which are far below the thermal comfort zone. The heating season is up to six months from October to the following March.

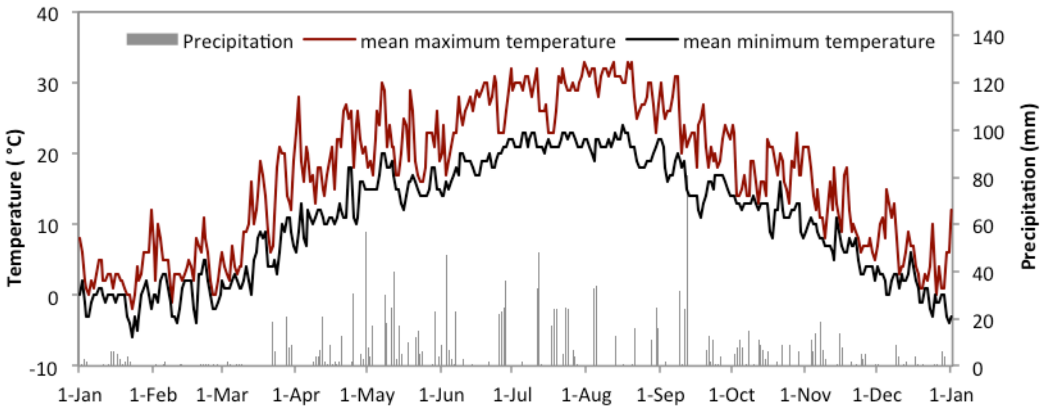

Figure 1 *The climate condition of Wulong during a typical year. (Data sources, www.accuweather.com)*

An in-depth study has been conducted since 2011. Based on long-term field measurements and investigations, a number of low-tech and lowcost strategies have been proposed to improve the indoor environment quality. We found the potential of heat recovery from cooking activities and upgraded traditional heated-wall system as the heat source. In this paper, the present conditions of thermal environment, indoor air quality, energy consumption and occupancy schedule have been discussed in detail. And the innovative heated-wall system and a possible house layout are introduced. The design intends to rediscover localization by using locallyavailable materials and tradional building technologies in an innovative way. The indoor thermal comfort and indoor air quality can be improved and comply with the features of occupants' life pattern. The strategies and techniques we proposed have broad-range applicability in HSCW zone. Community discussions were held during the whole design process and a pilot building is to be built there for future assessments.

METHODS

Respectively, four field investigations on indoor environment qulity (IEQ) were conducted in August 2011, April 2012, January 2013 and February 2014, in a remote village of Wulong County, Chongqing Province, China. Both questionnaire interviews and quantified measurements were applied. A total of 105 households participated in the questionnaire surveys, which includes 47 valid questionnairs in summer and 58 valid questionnairs in winter. The investigation included energy consumption of the household, heating method, health condition and 24-hour occupancy schedule. The subjective thermal comfort questionnair survey was also carried out, including thermal comfort vote (TCV), thermal sensation vote (TSV), thermal satisfaction and expectation. Certain scales and remarks are attached to these votes. TCV has a five-point scale from 0 to 4 (0 represents comfortable and 4 is limited tolerance); TSV has a seven-point scale from -3 to +3 (-3 is very cold and +3 is very hot); Thermal satisfaction has four remarks from unsatisfied to satisfied valued -1, -0, +0 and +1, respectively (-0 means “just unsatisfied” while +0 means “just satisfied”).

Mean while, the thermal environment measurements were carried out during these four surveys, indoor and outdoor environment parameters were recorded by auto-loggers for at least 72 hours each time. The thermal and luminous performances of rural houses in different seasons have been discussed and presented in our former papers. For more detailed information pleases refer to those previous studies. Field measurements of indoor air quality (IAQ) were only performed in February 2014. The indoor CO concentration, CO2 concentration and particle matter in four typical kitchens were monitored for 24 hours. Detailed Information of the Instruments **are shown in Table 1**.

Table 1. Detailed Information of the Instruments

Physical Quantity	Instrument	Accuracy	Data Intervals
PM2.5	Dust Trak8520	± 0.001mg/ m3	1 minute
CO	Q-Trak 7565-X	±3% or ±50 ppm	5 seconds
CO_2	EZY-1	±75ppm	5 minutes

OBSERVATIONS AND RESULTS

Energy Sources and Consumption

According to survey, wood and liquefied petroleum gas (LPG) are the main energy sources for cooking while wood, charcoal and electricity are used for heating. On average, 16.7% of the household income is spent on energy. During heating season, the everage energy consumption of wood and charcoal are 536kg and 126kg per household respectively. And due to the increasing heating demand, the monthly everage energy consumption of electricity is 305kWh per household while the amount is only 178kWh in summer. The energy price of wood is 0.25 RMB/kg and charcoal is 2.8 RMB/kg. Residential electricity price is 0.55 RMB/kWh.

Figure2 is composed of photos and thermographs of traditional heating and cooking methods. The locals adhere the concept of 'interval heating and spot heating'. Instead of heating the whole room, families or neighbours gather around a basin of charcoal or an open fire pit. High efficiency biomass stove are also applied in recent years. The traditional cooking stoves are widely used, burning woods and agricultural wastes. These inefficiency stoves cause the indoor air pollution. To make it worse, people often use part of the kitchen as living room in a traditional house, which leads to higher exposure to particle matters and harmful gases. As for concrete house occupants who usually have better incomes, using electric stoves and electric heating lamps is a common choice. Although it is less polluted, it significantly increases the energy consumption.

Figure 2 *Traditional heating and cooking methods used by local residents.*

Subjective Votes

About 34.5% of the respondents were dissatisfied with the present heating methods for hygiene problems or high levels of consumption. 96.6% of the respondents expected their houses to be warmer during the winter. TSVs for indoor thermal enviroment were -1.76 and -1.78 (close to cold) for winter daytime and nighttime, respectively. TCV was 1.18 (between slightly uncomfortable and uncomfortable) and the result of thermal satisfaction vote was -0.38 (between unsatisfied and just unsatisfied). These results illustrate the necessity of improve the thermal conditions in winter. Low temperature and high humidity lead to higher risk of rheumatic disease and even higher mortality rate in elderly during the winter. About 47.4% of the respondents had arthritis or rheumatism disease. The prevalence rate increased with age. This rate increased to 66.7% in the age group of over 60 years old.

Indoor Air Quality

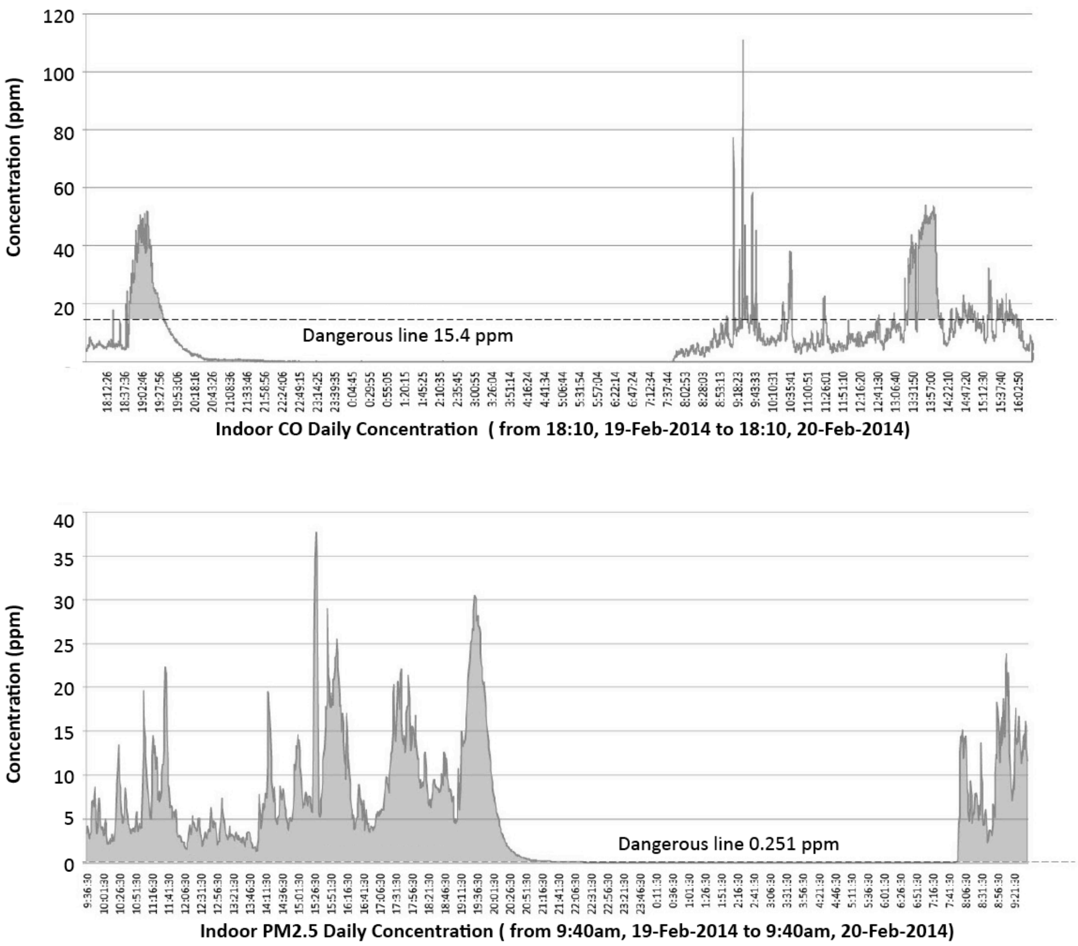

Figure 3 *Daily concentration of PM2.5 and CO of a vernacular house with traditional cooking stoves.*

The indoor air pollution is quite serious due to the lack of ventilation design and incomplete combustion, particularly for tradtional houses. As shown in Figure 3, the peak value of PM2.5 concentration in a tradtional house was 48.055 mg/m³ while cooking which was ten times higher then that of the concrete house. The peak value of CO concentration was 28.3ppm, which was eight times higher then that of the concrete house. The peak value of CO2 concentration reached 662ppm in daytime while the valley value was 423 ppm in nighttime. These air quality indicators overrun the limitation of national standard thus increase the risk of hypertensive disease.

Life Patterns

A 24-hour occupancy schedule was formed based on questionnaire survey and observational survey, **as shown in Figure 4**. It inllustrates the potential of using the afterheat of cooking activities as heat source for living room and bedrooms. The activities in living room and bedroom peaked right after cookings.

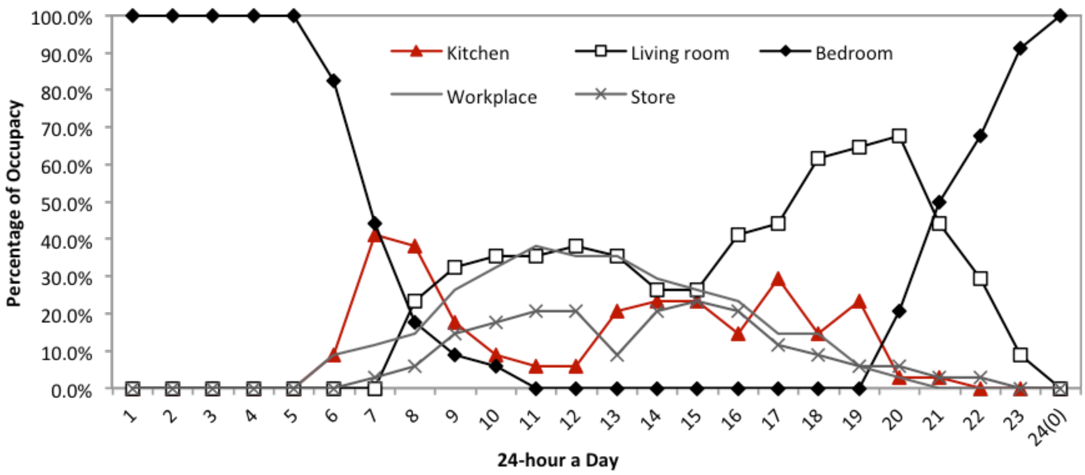

Figure 4 *24-hour occupancy schedule in winter based on field survey.*

DESIGN STRATEGIES

Design Intends

The design aims to support a more comfortable and healthier living condition without extra energy consumption and investments, by the properly building layouts and the innovative heated-wall system. It also takes the unique life patterns of local occupants into account, making efforts to minimize the total heating demand by continuing the concept of 'interval heating and spot heating'. A house menu is provided to maximize the flexibility and personalization. The economic cycles of households are also considered. Occupants can run small business, keeping rural livestocks, or processing farm products at home. Several design strategies and techniques have been applied as follows.

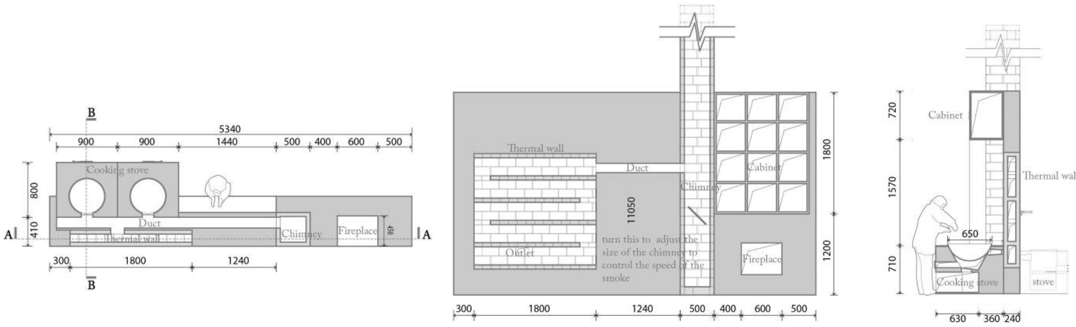

Figure 5 *Detailed drawings of the heated-wall system*

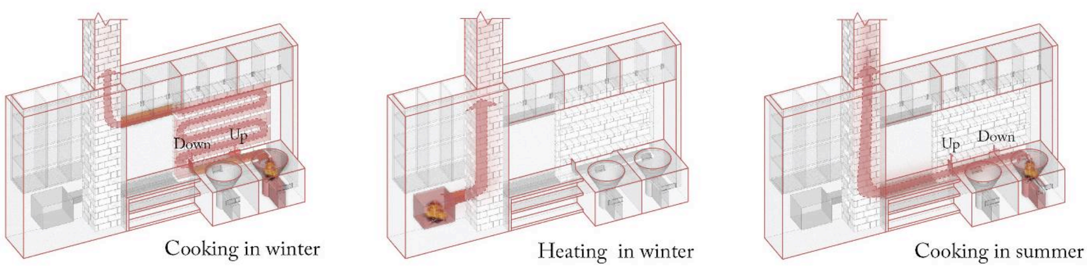

Figure 6 *Running modes of the heated-wall system*

Innovated Heated-wall System

Heated-wall system is a traditional technique for heating in the northeast of China but rarely known by southerners. The cooking stove is connected to a hollow wall, letting the hot smoke exhausted from the wall cavity. In this way, the wall is heated during cooking and radiant heat to adjoining rooms. The wall is usually located between kitchen and bedroom. According to the study helded by Tsinghua University in 2008, the heated wall can maintain a relatively comfortable temperature for about two hours after the stove stops burning. The innovated heated-wall system we proposed here adds a fireplace on the other side, sharing chimney with the hollow wall, **As shown in Figure 5 and Figure 6.** The cooking stove uses biomass instead of coal, reducing the reliance on fossil fuels. The fireplace can be alternated by a high-efficiency biomass stove.

Buffer zone

With a proper layout, we can optimize the use of heated-wall system (**see Figure 8**).. The concept of “buffer zone" is applied to resolve the paradox of cooling in summer and heating in winter (**see Figure 7**). The core zone of the plan is composed of four spaces surrounding the heated-wall system. Insulation layers are only used around the core zone which is the main living area in winter. The core zone is surrounded by a buffer zone, which is semi-open space buffering the core from cold outdoors and playing the main living area in summer. In this way, the indoor environment quality is improved without extra energy consumption and little investments.

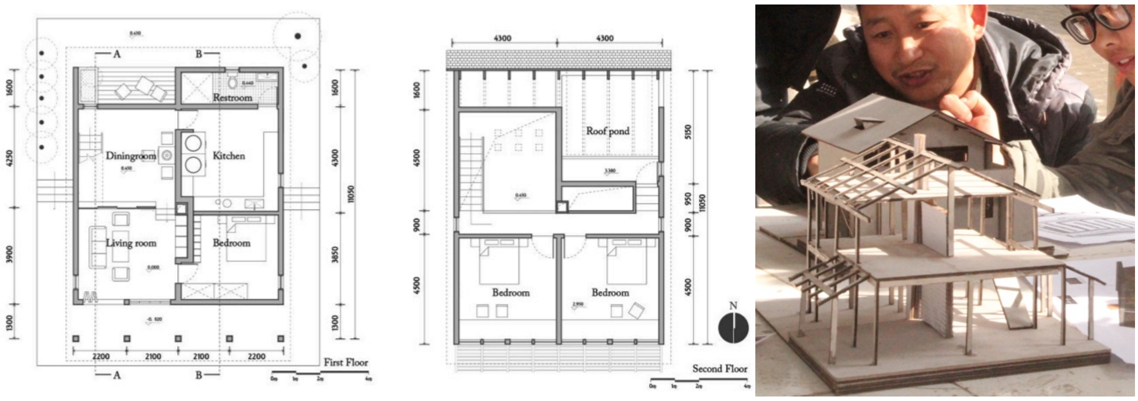

Figure 7 *Plans and working model of design proposal*

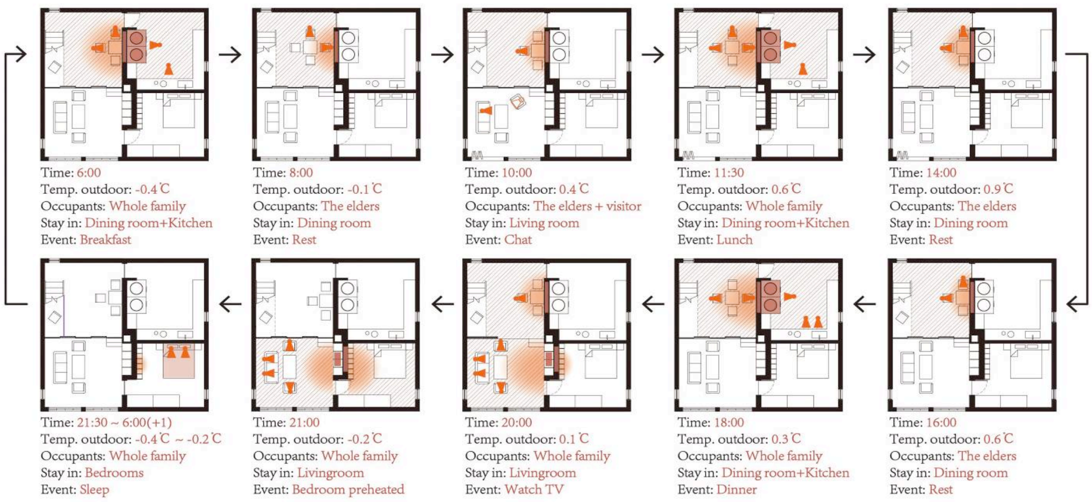

Figure 8 *Routine of the operation of heated-wall system harmonizing with daily life*

Localization

The construction can be performed by local labours, and the new building technique can be passed on and as a means of livelihood for them. All strategies are affordable, using locally available materials, and cost efficient even for people in less affluent area. Community discussions were held during the whole design process and a pilot building is to be built there for future assessments.

CONCLUSIONS

In this paper, based on in-depth field investigations and measurements, the thermal environment and indoor air quality of rural houses in southwest of China were analyzed. The authors disscussed the impacts of cooking activities on indoor environmental quality and the potential of heat recovery through occupant's life patterns. A series of low-tech and low-cost design strategies were proposed based on survey results. The strategies emphasized the utilization of an innovated heated-wall system for space heating, locallyavailable materials and a proper room layout to optimize the benefits.

ACKNOWLEDGMENTS

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Efficient Building Design Model Generation and Evaluation: The SEMERGY Approach

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ABSTRACT

The discordance of the available Building Performance Evaluation Tools with the capabilities and expectations of the design community and complexities related to data availability and accessibility are among the most important technical barriers against sufficient adoption of such tools to support and guide design decisions. On the other hand, the complexity of the design problem, a consequence of the large number of variables and options involved (e.g., financial, environmental, technical, and legal factors) calls for more effective approaches towards sustainable design optimization.

The SEMERGY project seeks to overcome such technical challenges through development of a user-friendly design optimization environment, tailored to suit the specific requirements and skills of the novice and professionaldesign community. The key feature of the SEMERGY environment is the incorporation of semantic web technology toward efficient search for and compilation of input information required for comprehensive analysis and evaluation of candidate design options supported by multi-objective decision support methods.

The present contribution briefly presents the underlying concept of the SEMERGY environment. It particularly focuses on SEMERGY's beta release, designed for optimization of retrofit projects in view of potential construction options. The current release accommodates requirements of novice user through a simplified web-based Graphical User Interface, the workflow of which is presented and discussed in detail.

INTRODUCTION AND BACKGROUND

Despite the advances in the development of Building Performance Evaluation (BPE) tools over the past decades, the adoption of such tools to support and guide design decisions has been relatively slow and their implementation mostly limited to certification purposes (Hensen et al. 2004, Pang et al. 2012). Most important stated technical barriers against adoption of such tools for sustainable planning and informed decision making are discordance of the available tools with the capabilities and expectations of the design community (Attia 2011), and complexities related to data availability and accessibility, which render the process of data provision for BPE applications cumbersome, error prone and time consuming (Mahdavi & El-Bellahy 2005). The SEMERGY project is an ongoing effort to facilitate the integration of performance assessment methods in the building design process to support sustainable design decisions.

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Identification of different design alternatives through a performance guided process is hampered by the complexity of the problem, a consequence of the large number of variables and options involved (e.g., financial, environmental, technical, and legal factors). "Manual" approaches toward identification of optimal solutions (mainly by trial and error) are time-consuming, expensive, and inconclusive. Hence, more effective approaches to optimization operations are being pursued, involving optimization platforms and associated automated procedures (Coffey 2008). SEMERGY explores developmental opportunities toward effective evaluation environments for comparative assessment of alternative design and retrofit options (Mahdavi et al. 2012a).

The missing link between users' simplified component representations (e.g., "external wall", "window") and complex specifications of real world products makes the efficient generation of building performance assessment models very difficult. In other words, it remains the task of end-users to map such simple notions of building components to appropriate real-world products that meet calculation procedures' informational requirements. The key contribution of the SEMERGY project is the demonstration of the potential of semantic web technologies toward populating the input data for building performance simulation models via the navigation of the extensive but currently ill-structured web-based information space. Currently, SEMERGY is focused (as proof of concept) on the scattered pool of building product and material data. However, data pertaining to building systems (e.g. heating and cooling systems, active solar components), as well as resources and documents concerning procedural, climatic, and financial (e.g. public funding) information that could be of value to designers and decision makers, can be processed and utilized in the same fashion (Mahdavi et al. 2012a, 2012b).

To accomplish this task, the SEMERGY system deploys two main strategies. First, information regarding building materials, elements, and components are obtained from various resources of the web environment. This information is preprocessed, restructured and augmented to meet the informational requirements of the integrated performance evaluation procedures. Using this reorganized and enriched repository, SEMERGY identifies design alternatives through a rule-based procedure. These potential alternatives are checked against building codes (pertaining, for example, to maximum allowed U-values). Thus, the corpus of possible permutations of the initial design could be efficiently reduced to a computationally reasonable size. Once the ordered set of feasible alternatives is constructed, it is made subject to a comprehensive evaluation process. Thereby, normative demand calculations, environmental impact assessment and cost estimation procedures are deployed. Upon completion of the assessment of the alternative designs, a collection of the best performing solutions is generated and presented to the user.

In summary, the SEMERGY system has links for i) user interaction (user interface), ii) applications and computational engines (reasoning interface), and iii) sources of information (semantic interface). The user interaction link is intended to involve both simple web-based templates for novice users and advanced building information models for professionals. The beta version of the web-based interface has been released and is openly accessible (SEMERGY 2014). The application link supports data exchange between the system and multiple analysis tools pertaining to energy calculation, lifecycle analysis, financial payback assessment, and optimization. The information link, which is the critical ingredient of the proposed architecture, is supported by Semantic Web Technology (Mahdavi et al. 2012a).

Previous publications presented and discussed fundamental features of the technologies embedded in the SEMERGY environment (Mahdavi et al. 2012a, 2012b, Ghiassi et al. 2012, 2013, Shayeganfar et al. 2013, Pont et al. 2013, Heurix et al. 2013, Hammerberg et al. 2013, Wolosiuk et al. 2014)

The present contribution focuses on the SEMERGY's beta release. Specifically, User Interface and workflow patterns are discussed in detail.

SEMERGY BETA FOR NOVICE USERS

Purpose and Structure

The current SEMERGY environment addresses the requirements of novice or professional users interested in a quick estimation of the thermal and environmental performance of their intended design and the alternative design possibilities within the limits of their financial means. The proposed alternatives include sets of construction options, for various building elements, entailing real world products available on the market. SEMERGY beta addresses at present optimization of retrofit projects.

However, SEMERGY for new buildings is under development. **Figure 1** depicts the structure of the SEMERGY environment. The reasoning interface of the present tool, incorporates a normative calculator for heating demand, a cost estimator, a simple life cycle analysis method based on the OI3 index (IBO 2014), as well as a multi-objective optimization procedure with an embedded automatic generator of alternative design options.

The semantic interface integrates an ontology of building products and materials. This linked repository is derived from two web-based product databases (MASEA 2014, BauBook 2014), enriched with cost data from various product reseller websites (e.g., OBI 2014), and other properties required for the alternative identifier logic. The data transition between the various system components is facilitated by the SEMERGY internal building data model (SBM), developed to comply with the requirements of the integrated and intended computation engines (Ghiassi et al. 2013).

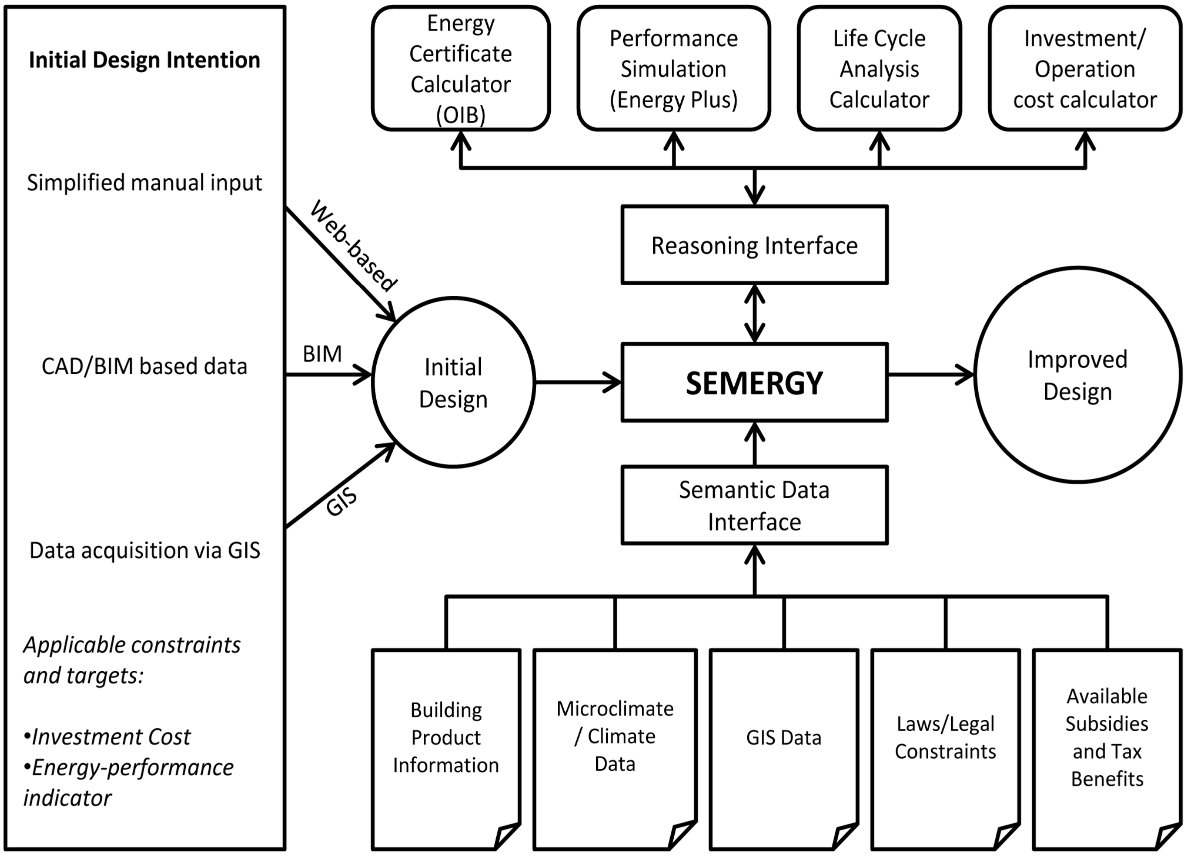

Figure 1 Structure of the Semergy Environment.

Workflow: Data Acquisition

General Information. The process starts by the entry of the location of the building to be refurbished. According to the location, the appropriate weather data and building codes are selected on the background for calculation and validation purposes. Next, the construction period and general construction method is selected **as shown in Figure 2**. This information allows the system to determine the relevent construction configurations of various building elements according to the common practice of the time of erection of the building.

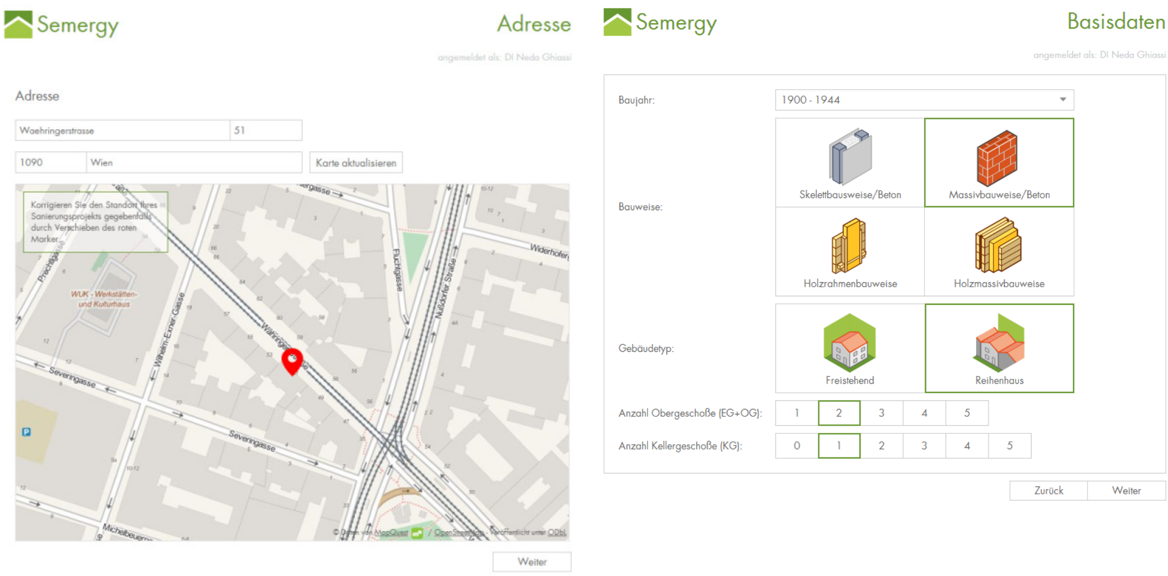

Figure 2 Left: Definition of building location by selection on the map or entry of adress; Right: Selection of construction period, type, and number of floors.

Roof Properties. Typical building floors can be easily represented in 2 dimensions and therefore even complex plans can be drawn with a simple 2D user interface. However, relatively simple building plans can result in complex roof geometries that cannot be represented in 2D. As a result, requiring users to input precise roof geometry necessitates a more sophisticated 3D user interface and places a larger data input burden on the user. Therefore, it is important, in view of simplifying the information input requirements on the user, to explore other alternatives. An algorithm has been developed to auto-generate a set of potential roof forms and select the statistically-proven best-fitting geometry based on a minimal set of input data (Hammerberg et al. 2013). Such an approach supports the generation of a roof approximation, suitable for more detailed performance analyses such as dynamic simulation, in the meantime, SEMERGY estimates the volume and area of the roof according to the roof type, height, angle and floor plan formation acquired from user **as shown in Figure 3**. This data suffices the purpose of the currently incorporated computational engines.

Building Systems Information. The heating system of the building is selected from a provided list of options. The current version of SEMERGY does not include building systems in the optimization process, but the next release is intended to address this issue.

Building Geometry and Space Properties. The geometry of the building is entered via drawing of plans on a grid. Help messages guide the user through the geometry entry process. Each building element of a different composition (e.g., external wall, fire wall, internal wall, etc.) is drawn with a different line color **as shown in Figure 4**. This layering is used on the back ground to associate the various enclosure elements with the appropriate constructions and boundary conditions.

Once the walls, doors and windows of each level are in place, the drawing is analyzed and various spaces (rooms) are identified. The user is then asked to select the function of each room (e.g., bedroom, unheated basement, etc.) and the height and sill height of the windows. Room functions are associated with templates of internal conditions, occupancy, lighting and equipments. This information is useful in case of integration of more sophisticated thermal performance computation methods such as dynamic simulation. For the time being, functions only determine whether a space is conditioned or not, to help identify the thermal envelope of the building. After the entry of all floor plans and assignment of space properties, the orientation of the building is set by rotating the plan on a map of the location. In order to capture skylights and dormers, the type, number, dimensions and orientation of the roof windows are entered by the user.

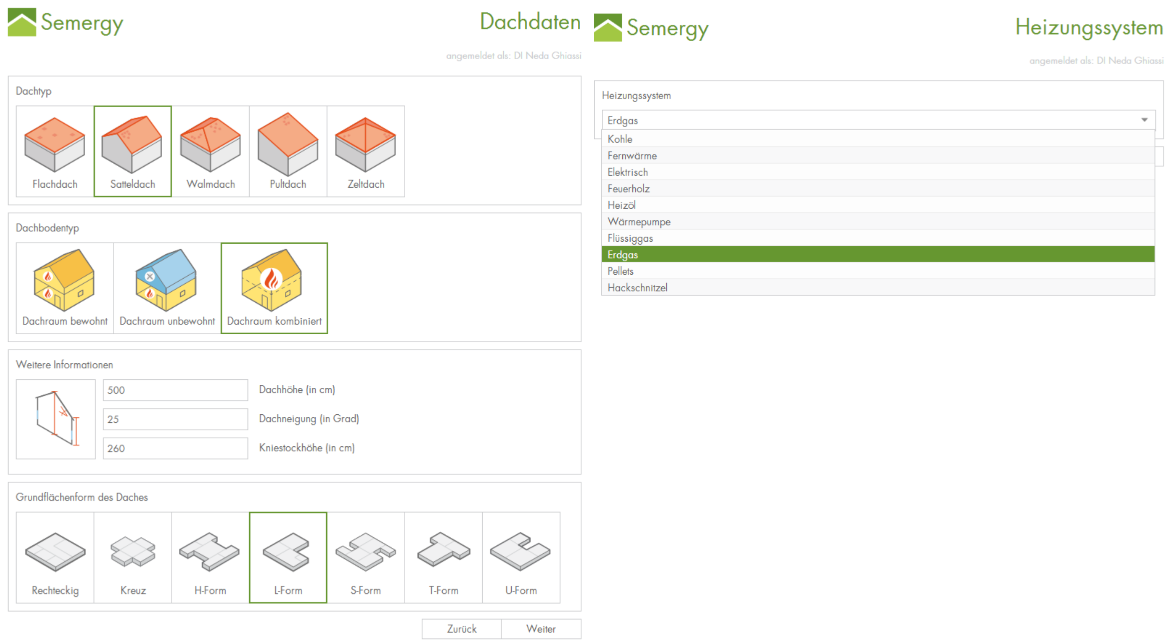

Figure 3 Left: Simplified roof description; Right: Selection of building systems.

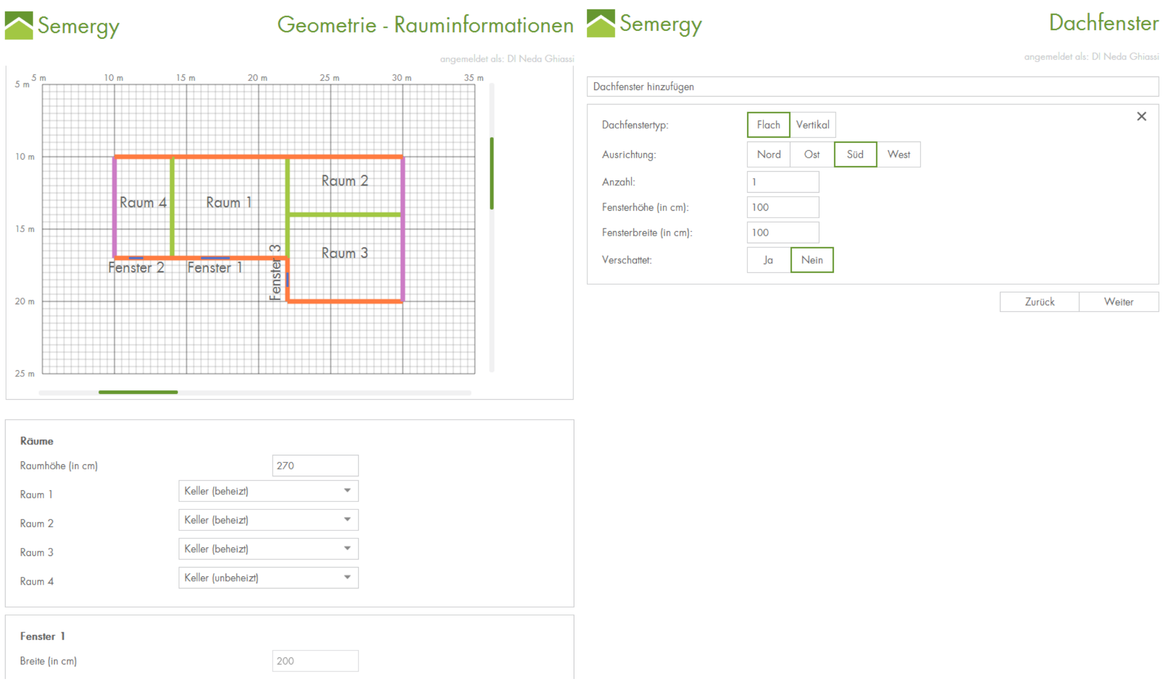

Figure 4 Left: Acquisition of floor plans; Right: Capturing of glazed roof elements.

Semantic Attributes of Building Components. In accordance with the construction year and type, set in the beginning of the process, the user is presented with a list of construction options for each building element. These constructions follow the common practice of the period, in which the building was erected and comply with the national norms on calculating the heating demand of historical buildings. The user may moderately readjust the layers of these default constructions to better represent the building **(as shown in Figure 5)**. They may also determine whether or not a certain construction is subjected to optimization. Detailed physical properties and cost information pertaining to the selected material configurations are retrieved from the building product ontology embedded in SEMERGY's semantic interface. As such, by simple selection of a construction from a given list of options, all information required for thermal, environmental and economic performance evaluations of the building are provided in the background.

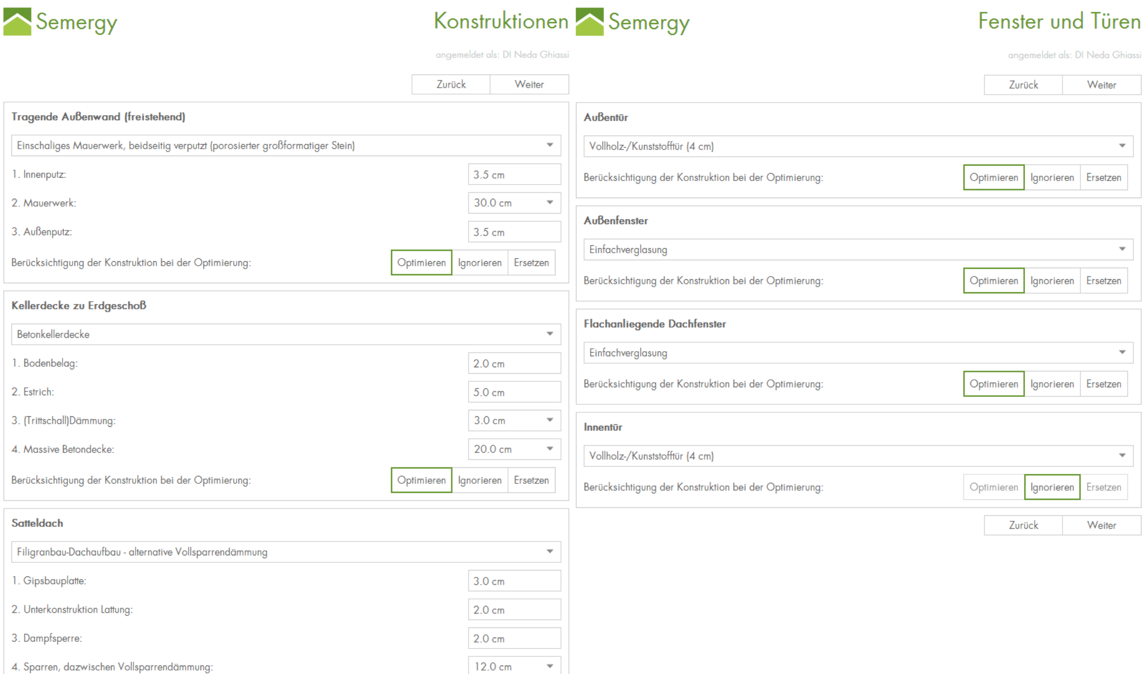

Figure 5 Selection and readjustment of semantic properties of various building elements.

Workflow: Evaluation and Optimization

Base Case Evaluation. Once the complete description of building and its components is acquired, SEMERGY generates a model of the building in the SBM format, a space-based three dimensional representation of the building, compliant with the requirements of the integrated performance computation engines. This model is subjected to performance evaluations. The system then provides the user with a base case assessment of the building's thermal performance. The results are presented to in the form of an energy certificate. The available budget for the refurbishment project is given by the user and the optimization process is initiated.

Identification of Potential Design Alternatives. According to the user-selected initial constructions, the integrated alternative identifier generates potential refurbished versions of building components by addition or removal and addition of new layers. These layers are selected from the ontology of building products by a rule-based logic that evaluates various properties of products for their conformity with the requirements of the construction subject to optimization. The resulting components are then re-evaluated in view of their compliance with building codes (e.g., maximum U-values).

Optimization Procedure. Once the scope of the potential (refurbished) combinations for each building element is determined, implementing the genetic algorithm method to reduce the number of computations to a manageable size, the pareto optimal set of solutions are identified according to multiple criteria of thermal, environmental and economic performance of the building. Each solution is composed of a full set of constructions for different building components. However, not all these constructions are modified as not all components are subjected to optimization.

Workflow: Communication of Results

The user can navigate between various solutions by prioritizing different optimization criteria. This is done by the help of sliders (**as shown in Figure 6)**, which cover the range of values of performance indicators (cost, heating demand and OI3 index) associated with different solutions. Obviously, selection of a value on one slider, affects the values displayed by others. Thus, the user may easily grasp the consequences of each decision (reduction of the budget or selection of more sustainable products) on all variables. A graph illustrates the pay-back time of the investment for each solution. Refurbished building elements of the selected solution are also displayed. The results of the optimization process can be downloaded as a PDF report.

Figure 6 Left: Navigation through optimization results; Middle and Right: Final report including retrofit suggestions and the expected performance level.

CONCLUSION & FUTURE WORK

The present contributed illustrated the recent state of SEMERGY's beta release. The current environment features a multi-objective optimization procedure for thermal retrofit projects and is supported by Semantic Web Technologies. This implementation demonstrates the capability of the proposed semantic approach in facilitating the utilization of the extensive, yet ill-structured informational AEC-ressources of the World Wide Web. Undoubtedly, intensive usability tests have to be carried out, to ensure the adequateness of SEMERGY to accommodate the requirements of novice and laymen users. In addition to usability tests, ongoing research includes improvment of the cost-estimation methods, integration of building systems and services in the computation process, addressing interoperability to CAD-, 3D-Drafting- and BIM-Applications, and augmenting functionality of the environment to support optimization of new buildings.

Readers of this contribution are invited to use and test the free-of-charge SEMERGY Demo available under https://www.semergy.net.

ACKNOWLEDGMENTS

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Integration of Outdoor Thermal and Visual Comfort in Parametric Design

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ABSTRACT

Parametric modeling tools are increasingly adopted in design practice. Various plug-ins for Grasshopper – the most widely used parametric tool – allow the creation of mathematically originated geometries from environmental data such as solar geometry, wind direction and velocity, radiation intensity, illuminance levels, etc. However, a critical look at the application of parametric methods in the practice of design reveals that their use is still predominantly based on aesthetical, structural and fabrication criteria. The opportunities that these tools offer to design strategies and components that are responsive to outdoor and indoor comfort conditions are starting to be explored at research level, but are rarely comprehensively integrated in the education and practice of architecture. To investigate the links between parametric form-making and outdoor comfort, a workshop at the Royal Danish Academy – aimed at the design of shelters – combined Parametric and Environmental Simulation Tools (ESTs) with the use of the most recent Grasshopper's plug-ins. In search of thermal and visual comfort optimization, the students employed these parametric design tools to achieve responsive geometrical design solutions.

KEY WORDS:

Parametric Design, Environmental Simulation Tools, Outdoor Comfort, Design Creativity.

INTRODUCTION

The past decade has seen the emergence of intricately-articulated surfaces whose design and production were enabled by the capacity of parametric tools. However, the way in which these design solutions have contributed to human comfort (e.g. thermal) has often not been analyzed in detail. This is particularly evident when looking at the parametric design (PD) of urban shelters. Complexly shaped forms have typically responded to fabrication and aesthetical principles, without holding careful consideration of users' comfort conditions (Turrin et al., 2012). Yet, the potential is there: their geometry and materials could positively affect thermal and visual comfort.
To explore the missing link between PD and comfort, a series of "parametric shelters" were designed by students of the CITA Master at the Royal Danish Academy (Cita.karch.dk, 2014). In a period of two weeks, design teams composed by 2 to 4 people approached climatically "challenging" urban sites in New York, Berlin, Honk Kong, Shenzen, Singapore, Reykjavík, and Madrid, a rural site in Barcelona, and a desert area in Iran. Each of these locations presented climatic conditions that limited their usability. The design of the shelters was optimized through

the parametric control of their overall shapes. The rationalization and modularization of their geometry was obtained with the integration of Environmental Simulation Tools (ESTs).

Design Comfort by Architectural Means

The design of shelters should mitigate external climate influences and facilitate, among other functions, the thermal comfort and daylight quality (Fig.1) of the spaces below and those adjacent. Several studies showed the influence of comfort on the ratio of utilization of outdoor spaces and on users' behavior (Nikolopoulou and Lykoudis, 2006). Outdoor climate studies indicate that the conditions expressed by the Physiological Equivalent Temperature (PET) – one of the most accepted models for outdoor comfort – are dependent on the radiation exposure and on wind velocity (Hoppe, 1999). Thermal comfort studies conducted by Bouyer et al. (2007) on envelopes of stadia showed the importance of geometry with respect to such parameters. For instance, designing the porosities of stadia (i.e., the capacity of the envelope and of the structure to control wind flow penetration) and the sky-opening factor (i.e., the sky view from the spaces sheltered) determines relevant differences in PETs (Turrin et al., 2012).

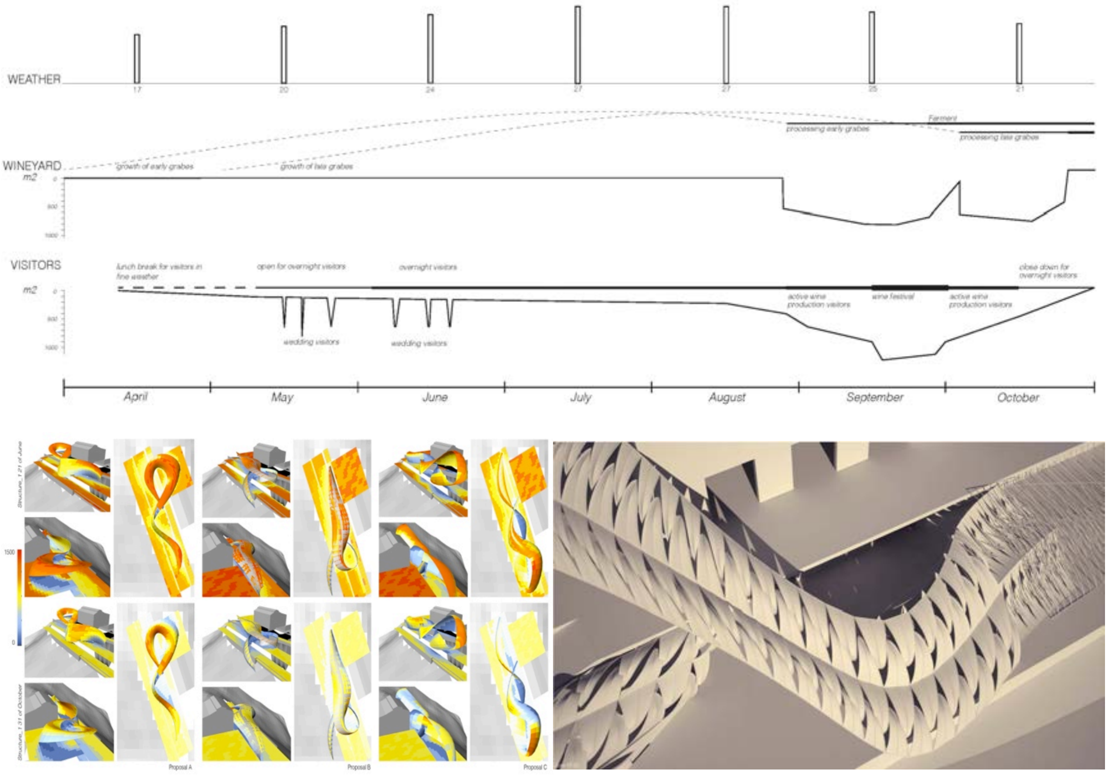

Figure 1. Valldaura (Barcelona). (a) The site, which includes a vineyard, hosts various activities and is exposed to continuously changing weather conditions. (b) First phase of the design exercise, when various shapes are studied according to optimal protection or exposure, depending on instantaneous radiation. (c) The structure is parametrically defined in order to enhance or impede wind flows and solar penetration as a function of comfort. Comfort number hours are predicted to be extended by 40% from April to October (Students: Ida Katrine Friis Tinning, Inès Klausberger, Tadeas Klaban).

TEACHING CONTEXT

Integration of Design and Analysis in a Parametric Environment

The workshop was centered on the use of Grasshopper, one of the most popular parametric platforms (author's article, 2014). There are several plugins that have been developed for Rhino/Grasshopper (Table 1). Some of the most recently available plugins allow an interface with validated Environmental Simulation Tools (ESTs), such as EnergyPlus, Radiance and Daysim (Roudsari, Pak, 2014). These plugins and tools are free and open source, and users can customize them based on their needs.

In the CITA Master workshop, a single model was used for design and comfort analysis, facilitating a smoother, more integrative, and efficient workflow (Roudsari, Pak, 2014). The benefits of integrating ESTs into the design process have been often discussed in previous studies (Weytjens et al, 2012). At the time of writing, however, discussion by non-developers of the actual application of such tools in the design process has rarely been documented (plugins such as Ladybug and Honeybee, used in the workshop, are very recent).

Table 1. Parametric Comfort Workshop: Design Process and Tools

Design Phase	Design Action	Parametric Modeling Tools (PMTs)
Climate Analysis	Weather file information was overlaid to digital models	Grasshopper - Ladybug
Performance Goals	Selection of one or more coupled performances goals (e.g. reduction of radiation when temperatures is over 24 degrees and wind is limited)	Outdoor Comfort Diagrams, Physiological Equivalent Temperature (PET)
Geometry design and performance behavior assessment	Design of a variety of geometrical shelter massing based on the repetitions of modules and assessment of their performances. Specific design of one component and analysis of its performance	Grasshopper - Honeybee, Ladybug
Inverse computing for design adaptability	Dynamic behavior of modules are determined on the basis of instantaneous weather conditions and user activity	Grasshopper
Verification	Design Solution are simulated for verification of their performances	Grasshopper - Honeybee, Ladybug,

DESIGN METHODS AND PROCESSES

Climate analysis

The design was founded on a thorough understanding of the weather data from the part of the students. Students learnt how the climatic conditions of their site transform over time in order to define adaptive design responses (Fig. 2). Even if the weather files were provided to students, it was considered that sites may have different microclimatic conditions than the one represented by the available data due to local factors such as urban fabric, materials, colors, soft/hard-scapes, etc. The use of the Ladybug plugin allowed to relate weather data to contextual characteristics (Grasshopper3d.com, 2014). This plugin to the parametric platform Grasshopper facilitates the graphical exploration of connections between the data available and geometries and materials designed. Multiple climatic variables (e.g., radiation and temperature) can be represented, overcoming limitations of tools such as Ecotect and Vasari.

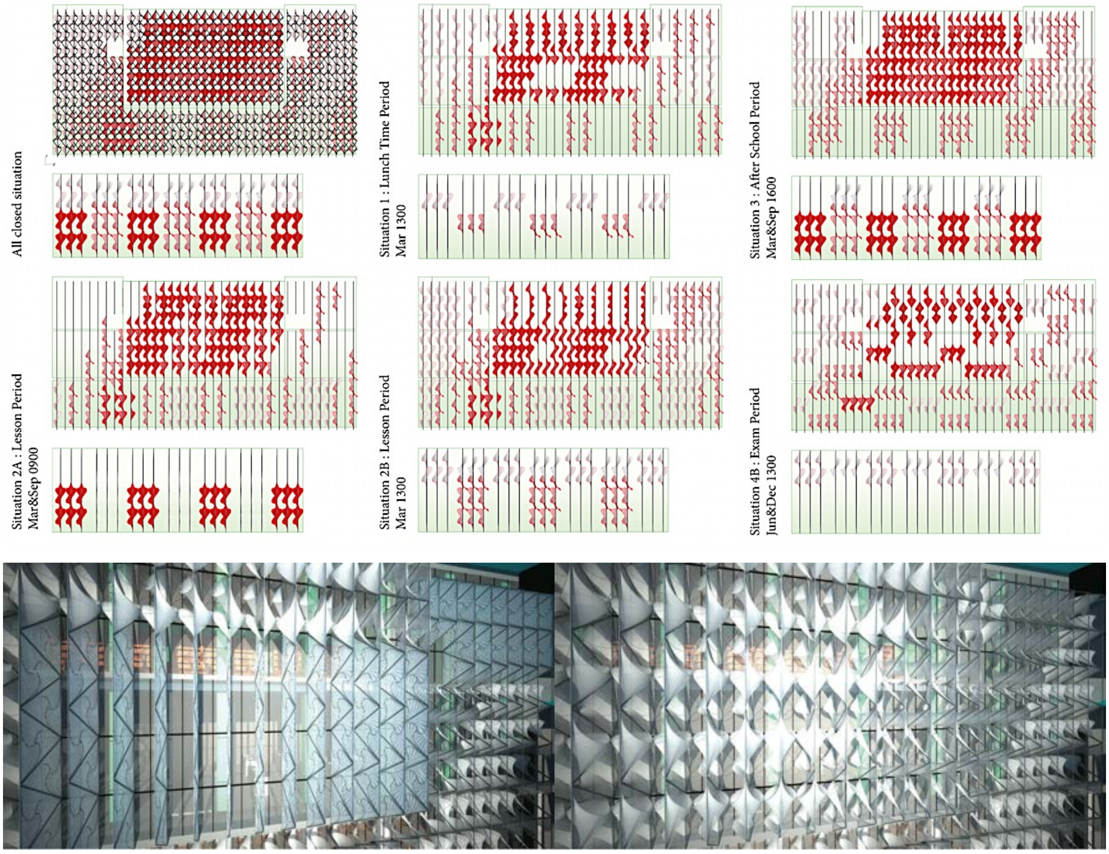

Figure 2. The design aimed to bring daylight in, and guide it through, a narrow court in Honk Kong. Indoor and outdoor illuminance levels controlled the position of façade reflectors. The courtyard, with the addition of the reflective components, receives an increases amount of daylight. Indoor rooms receive a well-calibrated light (a) The different positioning of the reflective components is based on sky conditions and users activities' requirements (c) Rendering of two configurations offered by the system (Student: Chan Chun Yin).

Setting numerical and time based performance goals

Multi-functionalism was considered as one of the design drivers: shelters had to be flexible and with open plans. The students envisaged final users' behavior, as it determined the comfort goals with measurable and meaningful indicators. Accordingly, and in order to contain the shelter design within achievable boundaries, a selection of numerical performance goals was made. The selection comprised two groups of indicators, respectively for thermal and daylight comfort. Each team started the design by setting time dependent performance goals for:

- Thermal comfort: PET or isolated factors influencing the heat-balance models of the human body were used (e.g., temperature, mean radiant temperature, shadows' hours, radiation, air direction and velocity, etc.).

- Daylight comfort: Illuminance and luminance values were adopted as design generators (Fig. 3)

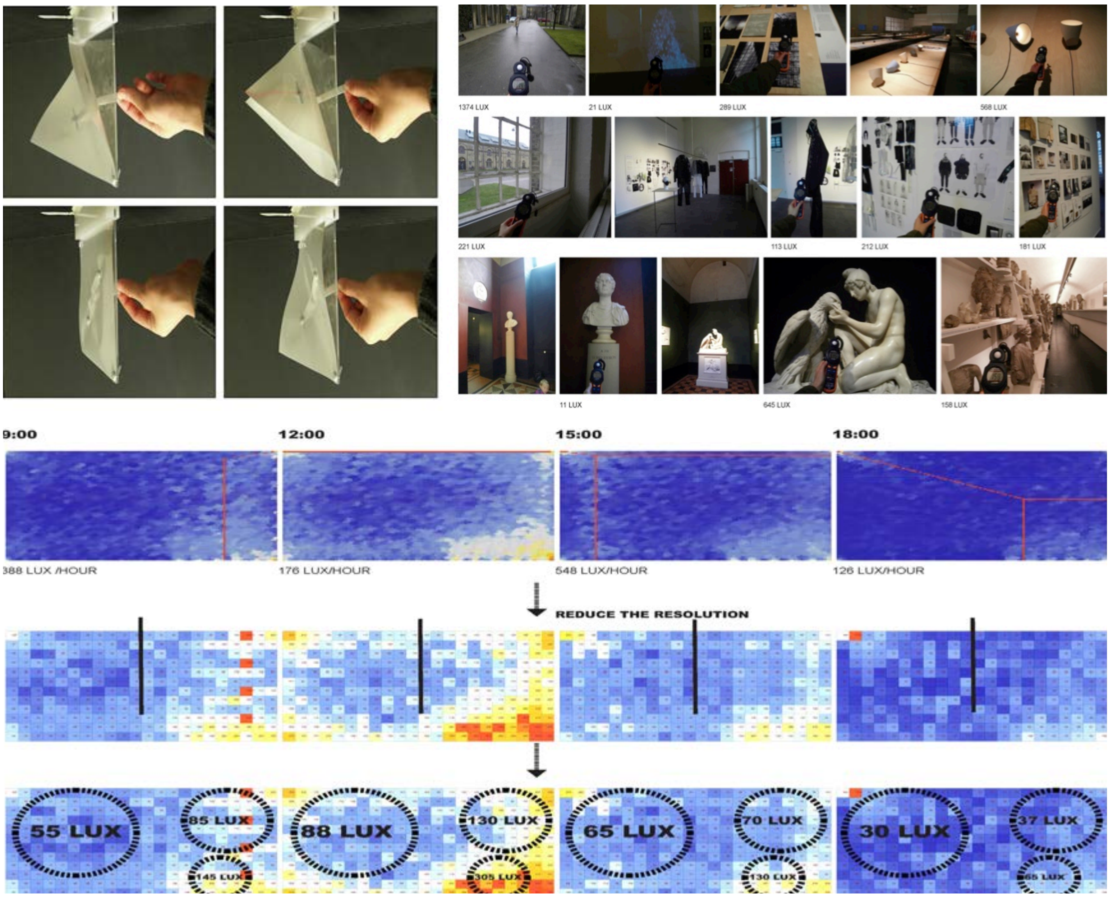

Figure 3 Design of an envelope system in Shenzen. The open-space hosts exhibitions (a). The facade opens depending on the type of exhibition light requirements. (b) Illuminance values were recorded in museums in order to study performance goals. (c) Possibility of illuminance variations were controlled by the façade system during a winter day (plan views) (Student: Wenyu Wu).

Geometric design and assessment of performance behavior

In this phase, Ladybug was extensively used to consider the implications of radiation and sunlight-hours. Integration of the plugin with Grasshopper allowed an almost instantaneous feedback on design modifications. The students created preliminary design concepts and simulated how they meet well-defined performance goals. Two key factors of their parametric system's design – geometry and material properties – highly influenced thermal and visual comfort. Another Grasshoppers' plugin, Honeybee, was integrated in the process to support detailed daylighting and radiation simulation using validated ESTs (Roudsari and Pak, 2014). Students could run several types of accurate image-based analyses to produce diagrams for luminance, illuminance or radiation.

Inverse computing for design adaptivity

A series of geometric reconfigurations were made so that shelters were able to react to climate conditions and users' thermal and daylight comfort. The focus was on components that constantly varied their configurations to adjust to weather variations and fluctuations of spatial programs. The parameterization process defined the dynamic movements of the components. Inverse computing techniques were used to determine such specific movements (Fig. 4). The systems designed are reactive to changing weather conditions and factors such as radiation, illuminance values, and wind speed and direction.

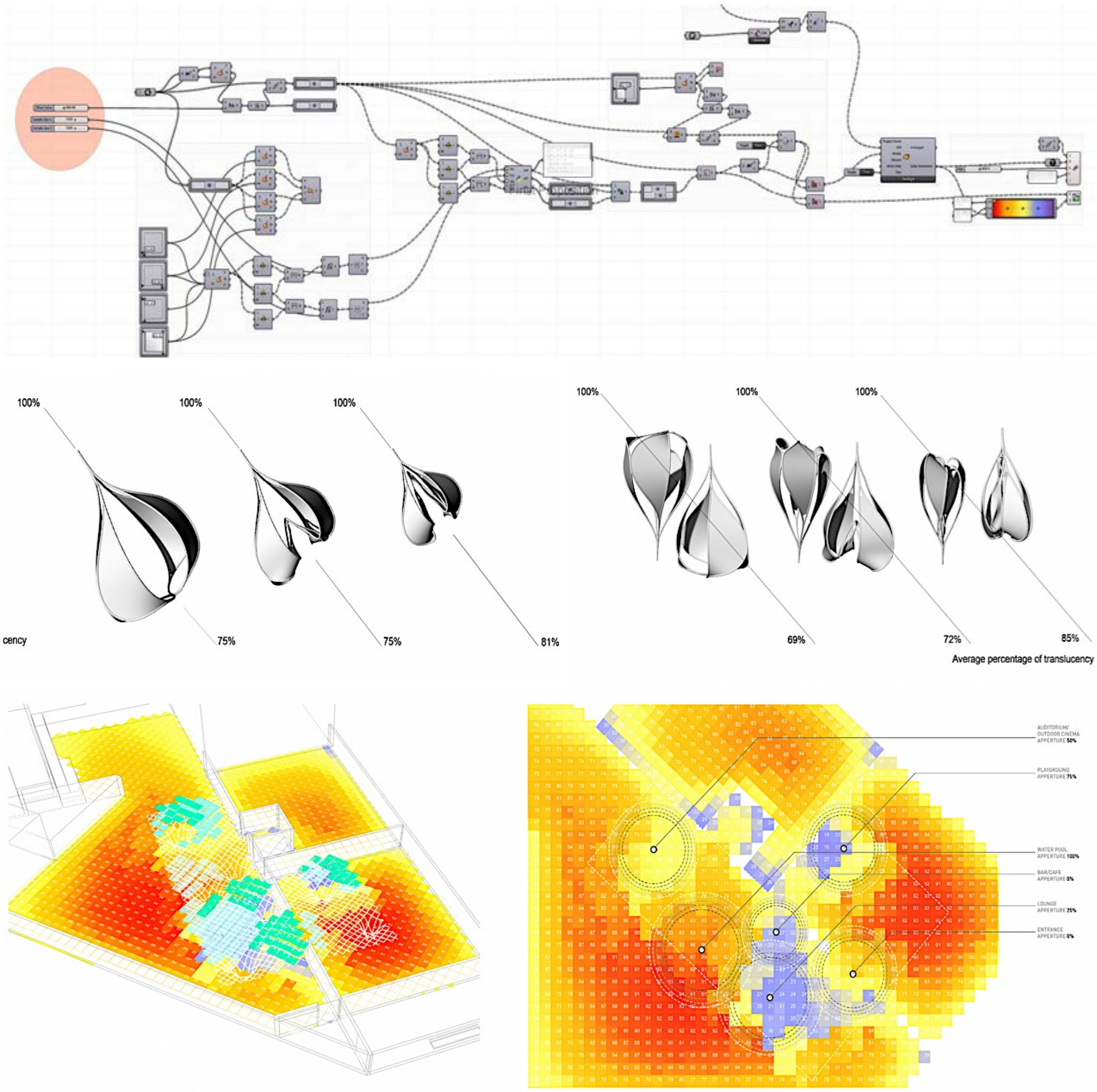

Figure 4 Design of a shelter in New York. (a) A Grasshopper "recipe". (b) Determination of the degree of opening of each parametric module. (c) The opening is function of solar irradiance and activities. (Students: Hulda Jonsdottir, Lukasz Wlodarczyk and Olga Krukovskaya)

DESIGN RESULTS

The qualities of all the shelters designed stemmed from their inherent link to the site. Projects located in New York, Madrid (Fig. 5), Barcelona, and Singapore (Fig. 6), experienced overheating. It was assumed that the air temperature of the spaces underneath was largely affected by the solar exposure of the spaces. The focus was therefore on reducing radiation when excessive. In opposite climates, with significant wind loads, such as the desert in Iran (Fig. 7), and the Icelandic city of Reykjavik (Fig. 8), protection from wind was considered crucial. Airflows in the spaces adjacent to the shelters depended on the incoming wind velocity, which is affected by their shape and openings. Finally, projects located in dense sites in Berlin (Fig. 9), Shenzen, and Honk Kong, focused onto creating visual comfort, while saving artificial lighting. The use of daylight as a primary light source enhanced environmental quality. Similarly to the principles informing the achievement of passive thermal comfort, daylight-oriented passive strategies aimed at reducing the use of artificial lighting with variable forms and reflectivity of materials.

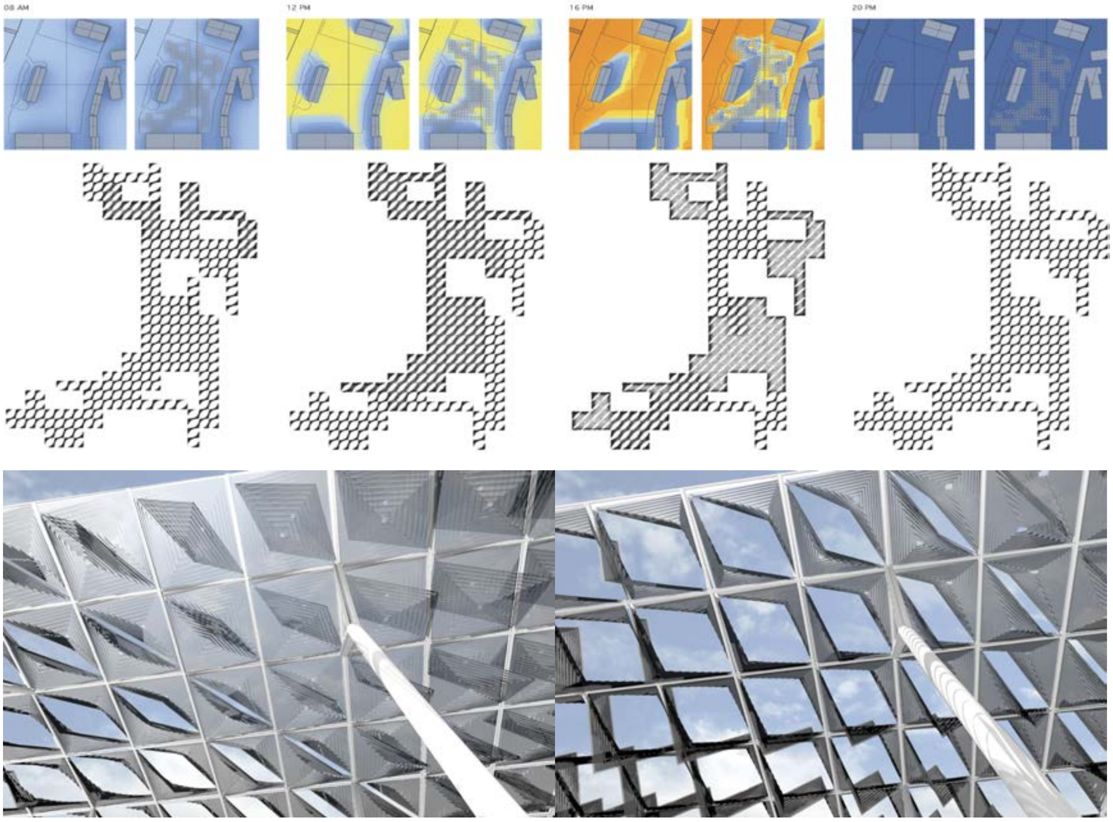

Figure 5 Radiation simulated at ground level is the parameter controlling the movement of a canopy hosting several street activities in Madrid. (a) Configurations of the system at different times of a day. Radiation is controlled only when necessary (i.e. when temperatures are above 24 to 30 degrees, depending on wind velocity) (Students: Huen Cheying, Lo Chen-Chi, Annika Nora Richmond).

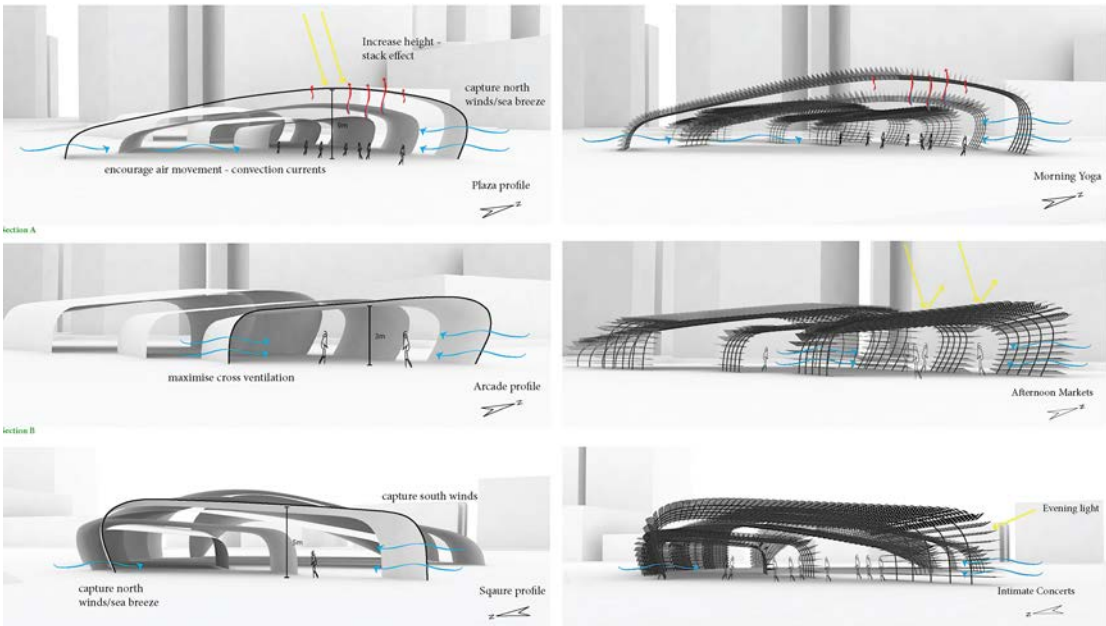

Figure 6 Parametric shelters in Singapore. (a) A series of sections shows how natural ventilation, radiation, and reflected light from surrounding buildings are integrated in one model where massing and components act as a system that increase thermal and visual comfort (Students: Mattias Lindskog, Lyn Poon, Karoline Wæringsaasen, Thyge Wæhrens).

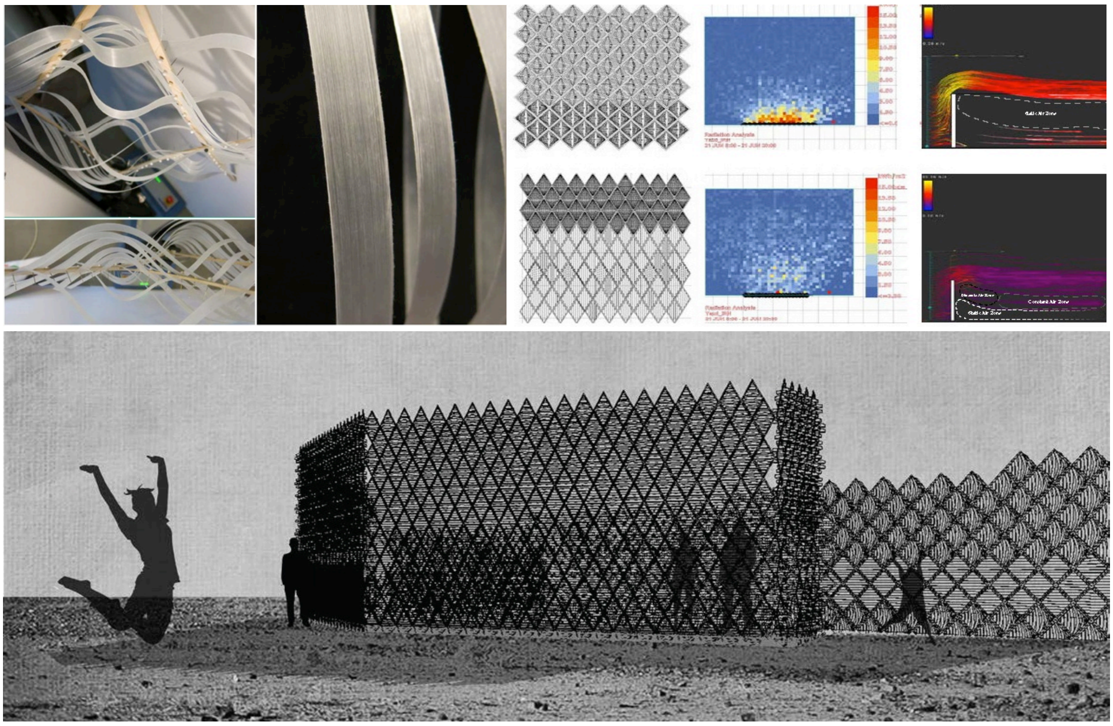

Figure 7 Iran. (a) Simulated wind flows and solar radiation are the parameters controlling the mechanic movement of flexible strips inserted into rhomboidal components. (b) These are hosted within a series of vertical wind shelters (Students: Zeynab Zaghi, Jens Jacob Jul Christensen).

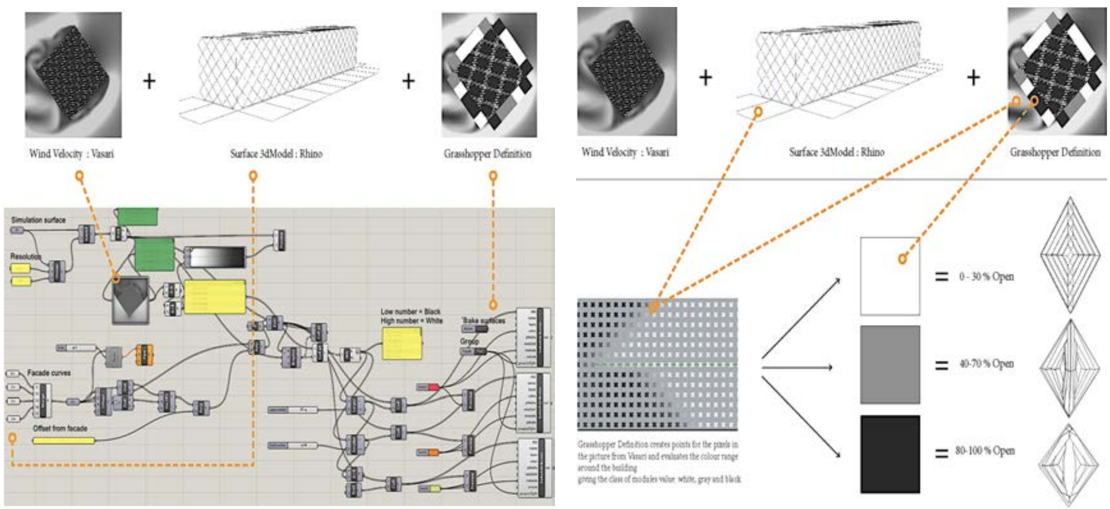

Figure 8. Due to high wind frequency and velocity, outdoor spaces in Reykjavik are quite uncomfortable for a large part of the year. The project looked at controlling wind flow in a public market. Pressure coefficients from rudimentary CFD models were used to control the façade permeability to air (Student: Kristjana Sigurdardottir).

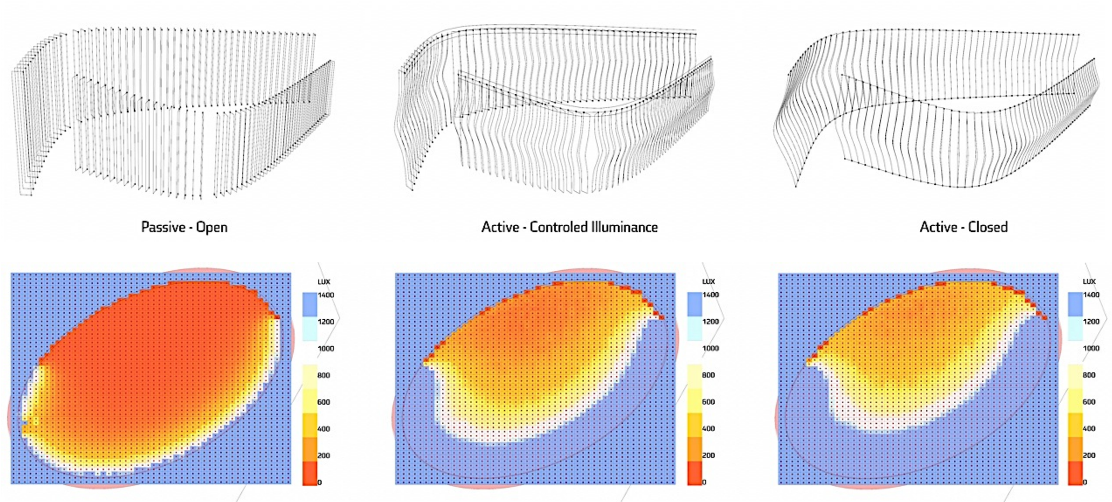

Figure 9 Berlin. A series of vertical fins were parametrically controlled linking their elastic deformation to targets of illuminance levels. Since the site is a large open space, creating differentiated visual conditions was seen as a stimulus for users' wellbeing and engagement (Student: Anders Per-Kristian Hansson).

CONCLUSIONS

Parametric modeling significantly increases the opportunities for climatic design.

The workshop attempted to break the mono-disciplinarity of most teaching approaches to parametric design where geometric inverse computing are often solely based on fabrication or structural roles, for which a larger tradition of conceptual morphogenesis exists. The series of designs elaborated by students illustrated how relations between structure, shape, and materials can be efficiently integrated with environmental considerations related to thermal and luminous comfort.

The findings indicated that it is possible and beneficial to integrate emerging parametric tools into the digital architectural and environmental design. These tools allow a 'transversal' approach to design information, and facilitate a decision making process based on the feedback loop between formal and functional relationships. Parametric design must be released from the constraints of 'parametricism' applied without any variations to all climates (however impressive its effects could be) and exploited to produce intelligent designs that embrace the full complexity of the environment.

A guided use of parametric tools seems to grant the opportunity to foster climatic awareness, intuition, and design skills in support of the students' decision making. At the workshop, students gained key insight into the microclimate conditions at play, and into capitalising locally available resources. They learned how the built environment is a highly complex system that involves many interdependent sub-systems.

AKNOLEDGEMNTS

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Session 3C : Control techniques for energy management

PLEA2014: Day 1, Tuesday, December 16
16:05 - 17:45, Grace - Knowledge Consortium of Gujarat

Energy demand, Thermal and Luminous Comfort in Office Buildings: a computer method to evaluate different Solar Control Strategies

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ABSTRACT

Many contemporary office buildings are characterized by large glazed surfaces, often located without any consideration about orientation. Without a suitable solar control strategy, this fact implies several problems related to visual comfort, thermal comfort and energy demand, which is mainly related to HVAC and, to a smaller extent, to artificial lighting. Moreover, if the office room is large, the values of physical parameters influencing comfort are relevantly variable from point to point, mainly as a function of the distance from glazed surfaces. Typically, daylighting requirements of occupants located far from the windows can conflict with the thermal comfort requirements of occupants located next to the windows. In this work a case-study is analysed. It consists in a medium size office room located in a typical office building, in an urban context of the Northern Italy. Different solar control devices and related control logics are compared; their effects on global comfort conditions and energy demand are assessed. The considered devices consist of different kinds of movable external slats, some of which incorporating PV cells. This analysis is performed by means of a specific software: "Ener_Lux", already presented in previous PLEA Congresses. Once defined the kind of devices and the related operating logic, the program simulates the dynamic thermal and luminous behaviour of the physical system, provides various comfort assessment index values and calculates the primary energy demand for HVAC and lighting.

INTRODUCTION

Many Contemporary office buildings are characterized by large glazed surfaces. Without a suitable solar control strategy this peculiarity implies several problems, both with regard to visual and thermal comfort and with regard to energy demand. The latter is mainly related, in Mediterranean climates, to HVAC and to a smaller extent to artificial lighting. Moreover, if the office room is large, the values of physical parameters influencing comfort vary relevantly from point to point; this variability is mainly due to the distance of the occupant from glazed surface. Consequently, for instance, lighting comfort requirements of occupants located far from the windows can conflict with the thermal comfort requirements of occupants located closer to the windows, requiring a reduction of entering solar radiation, because of overheating and glare.

These problems are particularly relevant in office buildings realised in Italy in the last decades, characterised by extended glazed surfaces, located in any façade with no care about orientation. In this

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work a case-study is analysed. It consists in an office room of medium size located in a typical office building, in an urban context of the Northern Italy. Different solar control devices and related control logics are compared, focusing on their effects on global comfort conditions and energy demand.

In particular, the considered devices are listed below.

1. Different kinds of external adjustable slat systems, with mirror-like or diffusing surfaces.
2. A double skin façade incorporating an adjustable slat system split into two parts: the upper part is composed by slats having mirror-like reflecting upper surfaces, whereas the lower part is composed by packable slats with diffusing surfaces.
3. Two kinds of adjustable external slat systems incorporating PV cells.

All of these devices are combined with an internal diffusing screen, aimed to avoid glare then the slats tilt allows the entry of direct radiation. As a general rule, the control logics are aimed to minimize energy demand and to allow daylighting for the maximum span. All of the analyses presented in this paper are based on computer simulations performed by means of software *Ener_Lux*, previously presented in PLEA Congresses, in particular at PLEA 2012 (Carbonari, 2012).

THE SOFTWARE

Software Ener_Lux is mainly aimed at the study of solar control devices and related control strategies. Therefore it takes into consideration the physical system composed by a room, its glazed surfaces, internal and external solar control devices (slats, blinds, overhangs and any element shading the opening) as well as the surrounding urban environment, including the building containing the room under investigation.

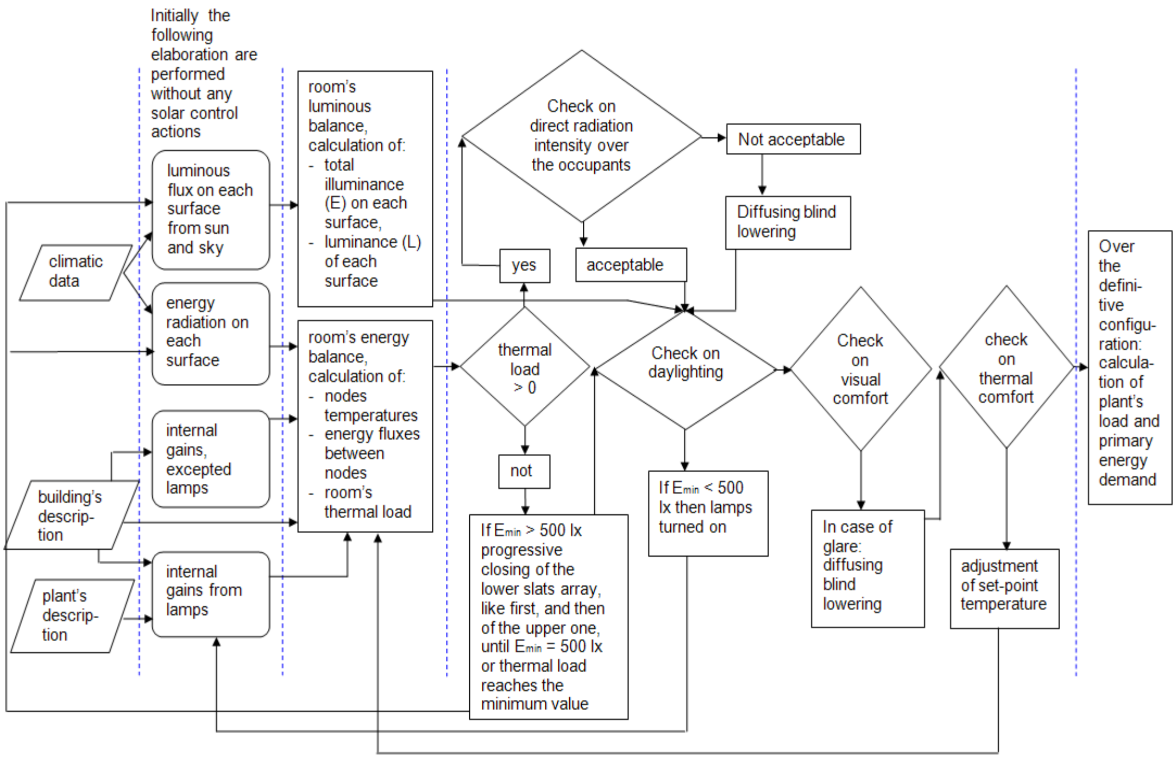


Figure 1 Scheme of the Ener_Lux calculation flow. The figure shows the behaviour of the program when referring to a double slat array, one of which is provided with mirror-like upper surfaces.

Once defined the kind of devices and its control logic, the program simulates the dynamic thermal and luminous behaviour of the physical system at hourly time-steps, and provides: Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) (Fanger, 1970) and Daylighting Glare Index (DGI) values, Hopkinson et al. (1963), together with other controls about the visual environment quality. Then it calculates the energy demand for HVAC and artificial lighting.

When adjustable devices are simulated, all the solar control actions aimed to maintain thermal and luminous comfort, such as slats tilting or screen lowering, are automatically simulated: in such cases, the program modifies the system geometry configuration and repeats the simulation of the hourly time-step. The check against visual discomfort conditions is performed only when the lamps are turned off, **as shown in Figure 1**.

The indexes used for the assessment of the visual comfort are calculated by means of an algorithm simulating occupants' visual field, **as shown in Figure 2**. Different kinds of glare are considered: veiling glare due to direct radiation impinging on the visual task, that can imply thermal discomfort too, big differences of luminance values between different points in the visual field, and glare due to large luminous sources (typically the sky seen through the windows), evaluated by DGI calculation. When one of these kinds of discomfort issues is detected, the program simulates a solar control action.

In case of thermal discomfort, averaged in the room as a whole, the indoor air set-point temperature may be modified to reach the true value of PMV (that has to be between -0.5 and 0.5 according to the standard ISO 7730) and the hourly time-step calculation is repeated. However, in this work this feedback is not performed.

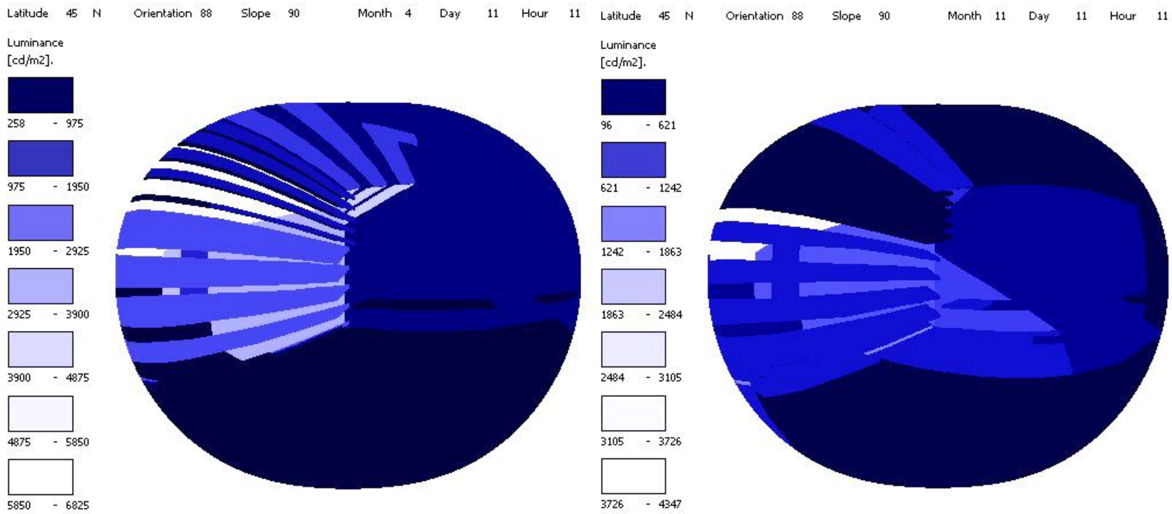


Figure 2 Simulation of an occupant's visual field at the same time on different illustrative days, in presence of double slat arrays. The slats of the upper array are mirror-like reflecting.

THE CASE STUDY

The case-study consists in an office room of medium size: 5.88 m wide along the façade, 6.18 m deep orthogonally to the façade, and with internal height equal to 3.27 m. The room is located in an office building of the industrial district of Venice (Marghera). The building presents an entirely glazed façade almost south oriented (with 22° West azimuth). In the local climate this orientation is the less favourable during the cooling period. Actually, this façade is equipped with a system of tiltable slats incorporating PV cells, **as shown in Figure 3 (b)**. At this side of the building a room at the second floor was chosen, to take into account the shading effects due to surrounding buildings. However, considering the distances from these buildings, there are not remarkable differences in solar irradiation between the second and the top floor. For comparison, a top floor room too has been simulated: when equipped with diffusing slats (see later) its total annual primary energy demand is 4.4% lower than in the case study.

The building structure is composed by reinforced concrete. Internal walls are in hollow bricks 0.08 m thick, with 0.02 m thick plaster layer on both the sides. Floors are built in hollow bricks and reinforced concrete: 0.24 m is the construction thickness, plus 0.06 m of screed and flooring and 0.02 m of plaster in the lower part. The only external surface of the room is the glazed one, composed by a double glazing of 0.006 m glass layers, and a 0.012 m air gap (overall U value: 2 $W{\cdot}m^{-2}{\cdot}K^{-1}$). All the other internal enclosing surfaces are considered as adiabatic.

Four occupants are located in the room, at different distances from the glazed surface. To assess the visual comfort level for each position the worst line of sight has been considered: i.e. the one implying the higher contrast in luminances within the visual field. Thus, the glazed surface has to be present in it but it is empirically assumed that it cannot occupy more than half the visual field; otherwise the occupant's eyes adapt themselves to the luminance of the external landscape.

Internal gains consist of: sensible and latent thermal flow from occupants (4 people · 65 W of sensible thermal power and 65 W latent), office devices (4 computers and 1 printer for a time average total power equal to 300 W) and fluorescent lamps (luminous efficacy: 91 lm/W, total power: 732 W).

To calculate the primary energy demand related to heating, ventilation and air conditioning (HVAC), it is assumed that the room is equipped with a full air centralized loop, and the daily time of utilization is from 09:00 (but the plant is activated one hour before) to 19:00. Although it is not the best efficient solution, it is assumed that the warm fluid is provided by a gas-boiler and the cold fluid by an electrically driven chiller (vapour compression chiller). Internal set-point temperatures are assumed to be 20 °C in winter and 26°C in summer (as prescribed by the Italian law), whereas in the middle season it is assumed equal to the daily average external temperature, because the clothing of the occupants is adapted to it. The relative humidity setpoint is assumed equal to 50% all over the year.

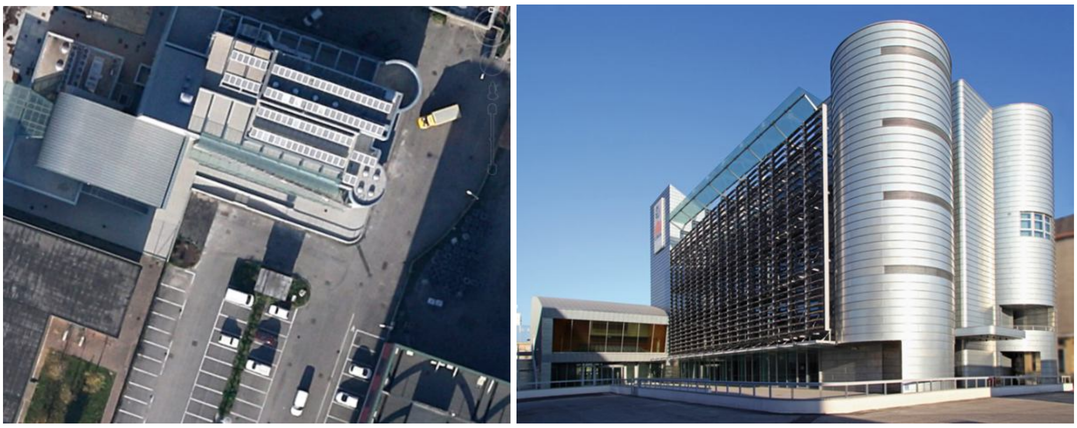


Figure 3 (a) The office building in its urban context, image from Google Earth (b) the actual configuration of the building (courtesy of Zintek Srl).

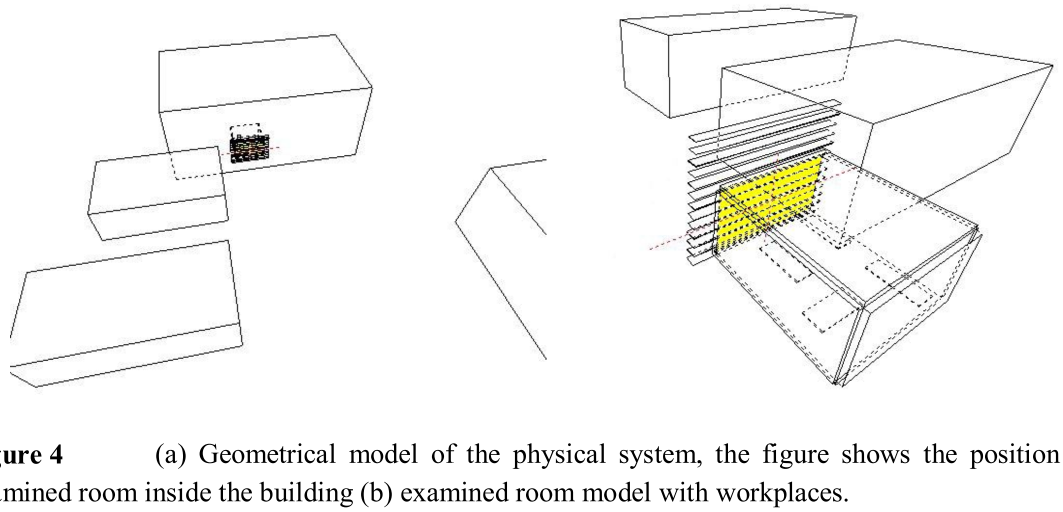


Figure 4 (a) Geometrical model of the physical system, the figure shows the position of the examined room inside the building (b) examined room model with workplaces.

THE EXAMINED SOLAR CONTROL DEVICES AND THEIR CONTROL LOGICS

The following solar control devices and related control logics are analysed and compared with reference to this office room.

External adjustable diffusing slat system. The vertical distance between slats (0.5 m) is equal to their depth (normal to the façade when the slat is horizontal). Slats surfaces are diffusing and their total reflection coefficient is equal to 0.6 for both the sides, whereas mirror-like reflection coefficient is assumed equal to zero. All the reflection coefficients used in this paper pertain to the total solar spectrum as well as the visible range. Slats are controlled by a seasonal logic: in each moment, slats are inclined at an angle that allows the entering of the only solar energy fraction that can contribute to cover the sensible thermal load, and avoiding overheating. Anyway, the entering solar radiation cannot be lower than the one required for daylighting, ensuring a minimum illuminance value (500 lx according to Italian standard UNI 10380) in the most critical workplace.

Double array of external slats. This system consists of two slat arrays. The upper slat array starts at 1.7 m from the floor and its slats have a mirror-like reflecting upper side (total reflection coefficient: 0.9, specular reflection coefficient: 0.9), whereas the lower side is absorbing (total reflection coefficient: 0.1, specular reflection coefficient: 0.0), to prevent downward reflected beams from entering the room. These slats are controlled in order to redirect the solar beams upwards inside the room, avoiding direct radiation on occupants and visual tasks. To avoid the entry of direct radiation in winter, the vertical distance between slats is reduced to 66% of their depth (i.e. 0.5 m · 0,66 = 0.33 m). The lower array is equal to the diffusing array described above. Also in this case the control logic is seasonal, but a little more complex. As a first step, the tilt of the upper array is adjusted so that the larger part of the incoming radiation is redirected upwards, whereas the tilt of the lower array is adjusted to allow the solar radiation to enter the room in the amount needed for heating purpose. When the lower array is completely closed and the entering radiation exceeds the required value, the upper array is adjusted to reduce it as well. This adjustment stops when the incoming radiation reaches the minimum value necessary for daylighting.

Double skin façade. In this case one laminated external glass (0.01 m thick) is present at 0.9 m from the previously described glazing. In the 0.9 m void a double slat array take place, close to the external glass. It is similar to the one described above, but in this case the slats, protected by the external glass, can be smaller and less robust. In particular, the lower array of diffusing slats can by packable to allow the entry of a higher solar power when required. The slat control logic is the same as for the double array system described above. During the cooling period the void is ventilated and it is assumed at the same temperature as the outdoor air, whereas in the heating period the minimum ventilation necessary to avoid condensation problems is provided, and the temperature of the air in the void assumes an intermediate value between the indoor and outdoor air temperatures.

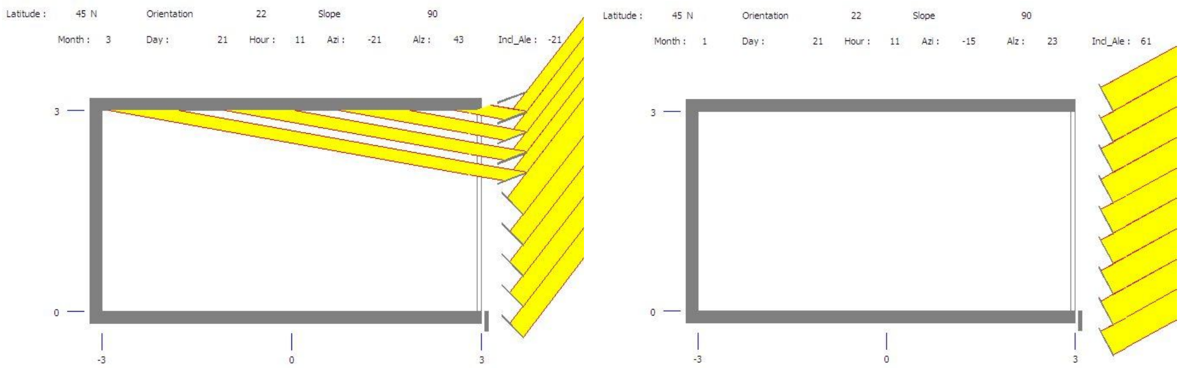


Figure 5 (a) Schematic behavior of the double array of slats and (b) slats incorporating PV cells.

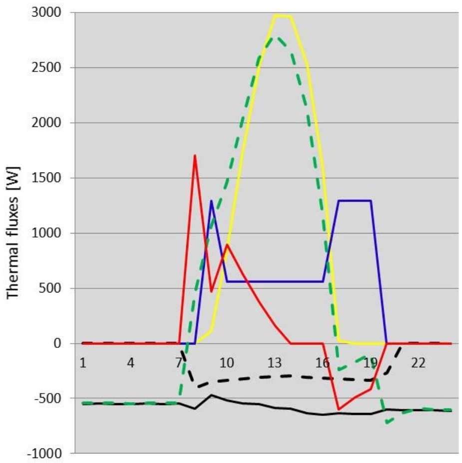
External slats incorporating PV cells. Two different types of slats incorporating PV cells were studied. In the first configuration (type A), the vertical distance between slats (0.5 m) is equal to their depth, but the PV cells occupy only 66% of the slat upper surface (and at the outdoor side), because in this configuration the remaining part is shaded for the most of the time. The reflection coefficient value is assumed equal to 0.2 for PV cells and 0.8 for the remaining slat upper and lower surfaces; therefore the average value is 0.39 for the upper surface. In the other configuration (type B) the vertical distance between slats is the same but the depth is reduced by 33%. This way a fraction of the direct solar radiation too enters the room during some winter periods and lowers the need for artificial lighting.

Moreover, the PV cells are less shaded, in particular as regards sky diffuse radiation, and their electrical production is higher. In both cases (A and B), initially, the control logic was finalized to maximize only the electrical production of the PV cells; therefore, the angle of incidence of solar beams on slat surfaces (the angle between the solar beam and the normal to the slat surfaces) was always minimized. Then, for type B, this logic was modified in order to allow the radiation needed for daylighting to enter the room, when available. This modification lowers relevantly the total primary energy demand, since the reduction in electrical production (limited to some hours of winter days) is negligible when compared with the achieved reduction in energy demand for lighting and consequently for cooling.

In all of the solar control systems described above, when the entering solar direct radiation can cause glare, an internal diffusing blind is lowered; it consist of a dark (grey 80%) metallic foil micro-perforated for 50% of its surface. Its light transmittance is equal to 50%, but it reduces the solar heat gain by 10% approximately. As a matter of fact, the energy absorbed by the foil is re-emitted as infra-red (IR) radiation, that cannot transfer through the glasses, and only the half part, approximately, of the short-wave radiation reflected from the foil can do it. This blind is used only in the heating period, since in the rest of the year the slats block the solar beam radiation.

ANALISYS OF THE RESULTS

The solar control devices are compared under two points of view: room total primary energy demand and global comfort conditions. Therefore, the thermal flows provided to the room by the plant, are converted into primary energy as a function of current values of boiler efficiency, chiller coefficient of performance (COP), and global system efficiency. The electric energy absorbed by the HVAC system as well as by lighting system is converted into primary energy by means of the related Italian electric system conversion efficiency (equal to 36%). The electric energy generated by PV cells is converted into equivalent primary energy using the same conversion coefficient and is subtracted from the total primary energy demand. For this reason, in some periods, the total annual primary energy demand appears as negative **as shown in Figure 7 (b)**.



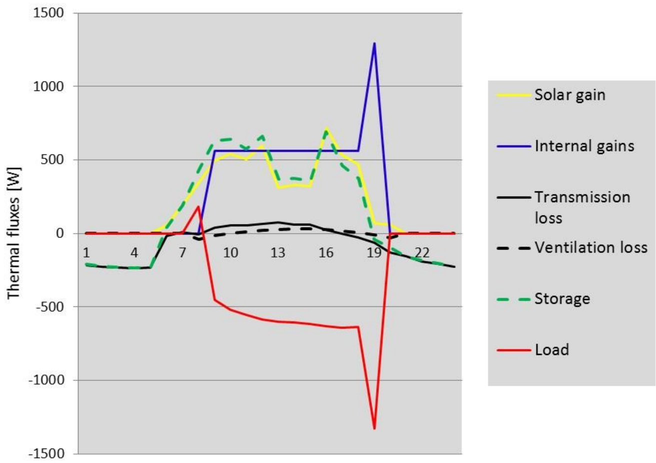


Figure 6 (a) Diffusing slats controlled by seasonal logic, room sensible heat flows (W) on a winter day (January 21) and (b) on a summer day (July 21).

Energy performance. The room under investigation is characterized by relevant internal gains and more than the half part of these comes from lighting system (732 W), when turned on. For this reason the cooling loads, present in winter too, are dominant in the composition of primary energy demand. In facts, with the exception of the first one/two hours at some winter mornings, when lamps are turned on cooling loads usually take place in winter too. For this reason, the level of daylighting achieved inside the room is decisive to define the suitability of a solar control system. Probably this situation can change adopting different lighting system, mainly consisting in task lighting by means of individual lamps located at each workplace (the related power can be reduced from 732 to 320 W), but the simulated lighting system is actually far more diffuse in Italian office buildings.

Among the devices without PV cells, the diffusing slats are the most energy efficient solution. The external double array with specular slats is less convenient, because of the lower total incoming radiation during the winter, consequently the artificial light is used for longer time and cooling loads are higher. The double skin system is fairly less convenient than the last one: the lower thermal losses reduce the energy demand for heating, but this benefit is overcome by the increase of energy demand for lighting and cooling.

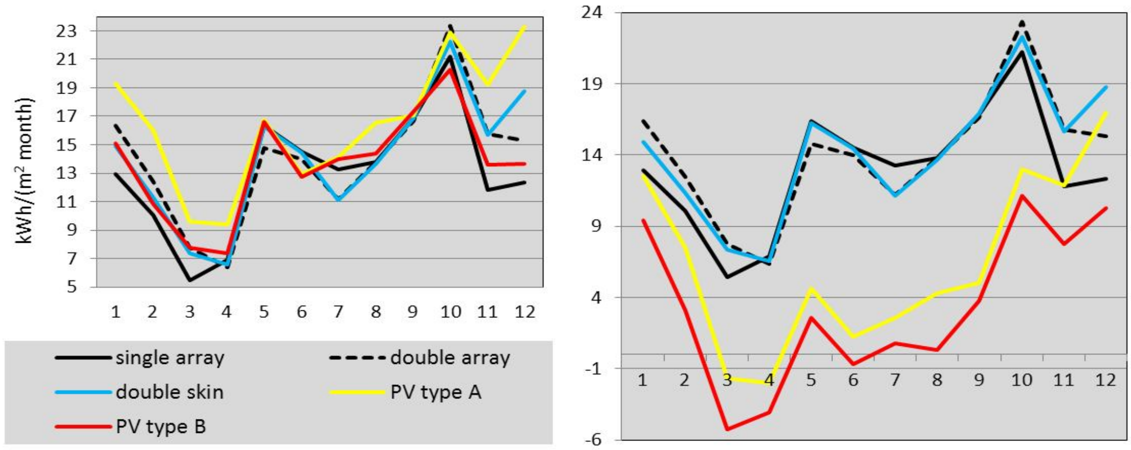


Figure 7 (a) monthly primary energy demand (per square meter of floor area) related to HVAC and lighting systems for various devices (b) total monthly primary energy demand, including PV generated electricity (with negative sign) [kWh/(m^2_{floor}·month)].

The annual electrical production of the devices incorporating PV cells is in the same order of magnitude as the room total energy demand, thus they are more convenient than other solar control devices. The first kind of device (type A) is controlled only to maximize the electricity generation, consequently the entering solar direct radiation is always blocked by slats and the entering solar diffuse radiation is reduced too. Therefore artificial light is turned on for longer time and, for short periods, useful solar gains are minimized, whereas the consequent increase in energy demand for lighting and HVAC corresponds to a small fraction (29%) of the primary energy equivalent to electricity generation.

Anyway, the best energy effective system is the one with less deep slats (type B), which allows a larger amount of solar radiation to enter the room, in particular when it is controlled in order to minimize the use of artificial lighting. In this case, in some months the room energy balance is positive: the primary energy equivalent to the PV electricity generation is higher than the room energy needs.

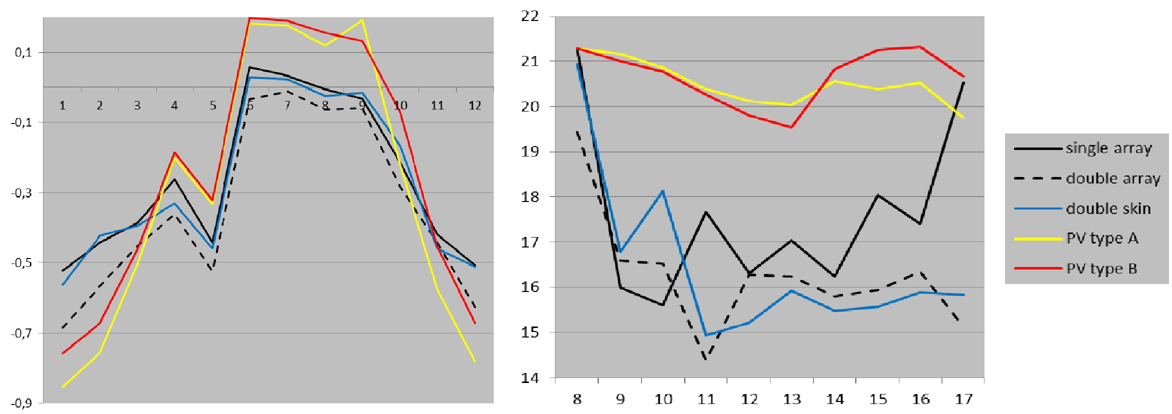


Figure 8 (a) spatially averaged monthly PMV values with different solar control devices (b) spatially averaged DGI values in in a summer day (July, 21) with different solar control devices.

Luminous comfort. A first comparison can be done on the basis of the total number of hours in which the DGI value is out of limits for at least one occupant and the internal blind is lowered. The limit value for DGI is assumed equal to 21 according to Italian standard (UNI 10840). Following this criteria, the external double array with mirror-like slats appears as the most comfortable configuration (the blind is used only in the 4% of the time) followed by the other two devices without PV cells, whereas all the devices incorporating PV present a worse behavior (the blind is used in the 37-57% of the time). In effect The DGI value exceeds the limit when the more luminous part of the sky is extensively visible, or when the internal average luminance is very low and the contrast with the visible sky is high, as it occurs in case of slats incorporating PV cells, particularly in type A, that assume every time the tilt necessary to block solar direct radiation. Another kind of discomfort can be caused by the solar beam radiation impinging on visual tasks; this is more frequent (during the winter) in case of double slats arrays.

At last, the two devices equipped with specular surfaces provide the higher uniformity of internal illuminance.

Thermal comfort. Using the internal air temperature as the indoor environment control parameter, the differences in the thermal comfort are mainly influenced by internal surface temperatures. Comparing different devices: comfort conditions are generally better with devices not provided with PV cells and controlled by a seasonal logic, **as shown in Figure 8 (a)**. In these cases the temperatures of internal glazing surface and internal surfaces exposed to the incoming radiation are higher during the cold season and lower during the warm season. The devices incorporating PV cells intercept direct radiation for almost all the time, but in the cooling season the entering radiation reflected by the slats is higher than in the other cases. Consequently, the internal temperatures are lower during the cold season and higher in the warm season. The spatial uniformity of PMV values is generally high (the differences are lower than 17% in winter and 2% in summer); particularly in the case of double skin (the differences are lower than 11% in the colder month too). This is due to the glazing internal surface temperature that is closer to the internal air temperature.

CONCLUSION

Overall, the less deep slat system incorporating PV cells (type B) is the most energy efficient device, particularly when controlled in order to allow the solar radiation necessary for daylighting to enter the room whenever available. In this last case, the PV electric generation is slightly reduced during some winter periods, but the problems connected to artificial lighting (such as lamps energy demand and cooling load) are appreciably reduced. Moreover in the room considered, characterized by relevant internal heat gains, the reduction of useful solar gains concerns only some short winter periods.

However all the systems provided by PV cells present worse performance regarding visual and thermal comfort. To avoid this problem it is possible to forecast some possible device evolutions with the purpose of combining the best energy and comfort performances, such as the following ones.

1. An array of mirror-like reflecting slats able to change the vertical distance between the elements, depending on the Sun position, thus entering solar radiation will be reduced only as a function of slats reflecting coefficient, but this kind of device is currently not available.
2. A double slat array with mirror-like reflecting slats in the upper part and slats incorporating PV cells in the lower part, controlled by the logic of type B.

NOMENCLATURE

PMV	=	Predicted Mean Vote (PMV) (Fanger, 1970),
PPD	=	Predicted Percentage of Dissatisfied (PPD) (Fanger, 1970),
DGI	=	Daylighting Glare Index (DGI) values, Hopkinson et al. (1963).

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Tuning Houses through Building Management Systems

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ABSTRACT

This paper departs from an analogy of sailing race instruments to demonstrate the potential of automation systems on the house performance and, more important, on impacting households for a more sustainable behavior. Sailing instruments have positively influenced the results on experienced sailors' speed and ultimately have confirmed their observations on nature cycles. We have presented two research projects for the development of Building Management Systems for a house that relies mostly on natural ventilation and thermal mass and another one, based on a complex conditioning system with a solar assited HVAC system, connected to a Phase Change Material thermal storage. Our argument is that if research on the sailing tournament America's Cup instruments soon became available to other sailing boats, systems developed to the Solar Decathlon houses' academic competition could, and should, be accessible to a great number of home owners. These two research projects give evidence that further research should be guided to more sustainable BMSs, which could significantly contribute to households' behavior changes and ultimately support dwellers reconnection to natural cycles.

INTRODUCTION

Burry, Aranda-Mena, Alhadidi, Leon and Williams (2013) presented a challenging statement that "compared to architecture, performance is more transparent in a high-performance sport such as sailing where it is clear that 'speed is good'." Although their approach to sail racing and architecture focus towards a different perspective, we would like to use it as a starting point to elaborate our argument.

Sailors can teach us about having their boat perfectly regulated. A connection between sailing and buildings has been presented by different authors, with a broad range of approaches (Murcutt, 2008; Lynn and Gage, 2011; and Burry et al, 2013). We believe that a house could be tuned in a similar way as sailors trim their sails and plan their racing strategies. Experienced high-performance sailors' success depends on their ability to understand the boat functioning and environmental changes and cycles. We would argue if it would be possible to stimulate in dwellers similar abilities found in these sailors.

"... And you work this house and you work most of my buildings like you sail a yacht. You have to work them so that you understand how to get the best out of the climate without having to aircondition." (Murcutt, 2008) In this remark, offered in a TV interview, Murcutt does not present a revolutionary concept. Actually, he raises a primitive concept forgotten in most contemporary houses.

Contemporary homes are no longer able to communicate their operation systems. The systems' complexity is usually hidden from the dwellers and does not support the latter engagement. Primitive communities' homes, on the other side, clearly displayed their technologies that united them to their

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place. Primitive dwellers, as sailors, understood their technologies, building performance and the direct environmental influence.

High performance sailing boats have embedded a great variety of technologies. These technologies support sailors' connection with the natural environment and boat performance awareness. Several of these technologies are brought by research for high-performance and high-cost competition enterprises, such as the most famous America's Cup.

"All through the 1980's the America's Cup was contested in Twelve Meter Yachts, and significant advances were being made in hull construction, sailcloth and panel layout, and in sailing instruments systems. But, perhaps more than the others advances, sailing instruments were beginning to change how boats were sailed. The information regarding wind angles and speed were better than ever, but being able to make calculations which could indicate how efficiently the boat was being sailed was what was changing the game for the world's best sailors." (Ockam, 2013a)

Sailors use polars as predictions of the ideal boat speed across a range of wind angles and speeds. Several sailing instrument systems can compute and display, in real time, polar plots of the boat target speed in the given current conditions. They offer to the crew information that allows them to judge how they are performing against the boat's speed potential. Their precision is quite important to the point that sailors such as Dennis Conner account for the polars' precision to their success in races. (Ockam, 2013b)

A dwelling performance is quite different from race sailing boats. The latter has to reach the destination before the other competitors. Boat speed is not the only parameter to define the winner, but it is surely decisive and sailors have always to search for the best speed in the particular conditions or strategies. In a house, users should seek for a sustainable comfort. Home sustainable comfort presents different variables to distinct dwellers and to their various activities (de Dear and Brager, 2002). Thus, there is no ideal performance modelling that could apply to everyone. Following this line of thought, it is important that users identify their comfort zone that could be applied to control natural and mechanical conditioning methods and even lighting levels.

Cruising boats do not have to beat competitors, but are highly influenced by innovations developed by high performance sailing. These technologies afford cruisers with a combination of boat performance, weather data and location conditions. These instruments do not move away sailors from environmental awareness, as building technologies have done in the past. On the contrary, they facilitate an understanding of environmental data as an integrated natural network. Primitive dwellings have been developed as devices adapted and adaptable to environmental conditions. Dwellers could feel wind shifts, see changing colours and smells. Weather could be predicted and the house prepared for extreme conditions. Modern building technologies have supported comfortable homes, better protected from weather extreme conditions, less dependent to environmental cycles, as well as more energy dependent.

We are so disconnected from environmental cycles that it is a difficult task to engage users in more sustainable habits. Sailing technologies can teach us to better understand environmental data in order to recognise our place on earth and better adapt our habits to environmental cycles. Most of our home technologies have been developed in times when energy and environment were not a major concern. We do not need to get rid of technology, but develop more efficient systems able to better connect our buildings and users to natural environment. Sailing technologies have performed this movement mostly because they have always depended on nature's cycles. Information has been a key issue. We have lost the use of our senses to acquire it, as primitive dwellers did once. Therefore, systems integrated to environmental data could support engaging residents to dwell with more sustainable habits.

This paper explores the development of two residential Building Management Systems and their user interface. The houses and their systems are quite different. They were designed for different continents (Australia and Brazil) but share some climatic similarities, as well as analogous relationships identified in high performance sailing systems and their potential impact on cruising boat technologies. Although the two management systems have broader applications, particularly related to energy generation and management, the discussions in this paper will focus on their thermal comfort systems. One of the houses relies on a hybrid and innovative HVAC system, while the other applies, with the exception of few days during the year, on passive conditioning and ventilation methods.

BUILDING MANAGEMENT SYSTEMS

Building Management Systems (BMS) applied to houses have become relatively cheap and widespread. However, they are mostly limited to integrate few home controls usually related to lighting, thermal conditioning, media and security. These systems are able to incorporate powerful applications similar to those found in sailing instruments. These applications should be more explored to afford updated data about house performance, as well as weather data. They may also support understanding of the house functioning, which has been lost throughout history, as our houses became more technologically complex. In order to provide a meaningful environmental impact, the houses should not only be technologically holistic. They should appear holistic to their users. House performance depends heavily on users and their awareness. The reduction of energy consumption, for example, depends on technologies but also, and heavily, on choices taken by users (Schipper, 1989; Socolow, 1978).

Building design and its technologies have the potential to involve and educate. Orr (1997) placed the argument that our buildings miss their potential to reflect a hidden curriculum embedded in design choices. He asked if "[t]hrough better design is it possible to teach our students [users] that our problems are solvable and that we are connected to the larger community of life?" Following his advice, designers should care about how dwellers perceive and understand their homes. Houses, as any building, should be adaptable to different environmental conditions and residents should aspire to have them tuned.

Sensors, actuators and BMSs' interfaces could act similarly to sailing technologies, in order to facilitate adjustments for tuning the house. They are able to provide updated data of the house performance and its systems, implementing automated functions towards dwellers awareness. If they become widespread, they could drive the development of affordable systems even for low-income housing. Although the experiments described below apply to relatively expensive houses, they demonstrate systems with a great potential for a relevant impact on more sustainable home behaviour.

THE ILLAWARRA FLAME HOUSE

The Illawarra Flame House is a small and high performance house developed for the academic competition Solar Decathlon (US Department of Energy, 2014), organized for the first time in Asia. Team UOW, lead by the Sustainable Building Research Center, University of Wollongong, designed, constructed, brought the house to Datong, China and won the Chinese Solar Decathlon, in 2013, attended by a total of 22 teams representing recognized universities around the world.

Team UOW has demonstrated a remodeling and retrofitting of a common and archetypal Australian house built approximately 50 years ago. The aim is to inspire national building industry and the general community that it is possible to transform the vast majority of Australian homes into stylish, affordable, and sustainable homes of the future. By upgrading an existing house, Team UOW took up the challenge set by the U.S. Department of Energy, China National Energy Administration, and Peking University's goals to "accelerate the development and adoption of advanced building energy technology in new and existing homes". With less than two per cent of Australia's housing replaced each year the Australian team believes that this retrofitting approach has the greatest practical potential to achieve significant economic and environmental gains across the country domestic built environment.

The Illawarra Flame showcases a radical, affordable and achievable blueprint and benchmark for retrofitting a typically Australian 'fibro' house. Fibro refers to cladding sheets constructed of asbestos fibre-reinforced cement. They are ubiquitous to Australian suburban streets. In addition to environmental concerns, recent increases in energy prices, the health implications of asbestos, and the poor thermal performance of these houses, have led to an urgent need for widespread upgrading. (Team UoW, 2013)

The Illawarra Flame features a Solar Assisted HVAC system that integrates an air based Photovoltaic-Thermal (PVT) system, a Phase Change Material (PCM) thermal energy storage and a standard reverse cycle air conditioning system. The house holds two types of Photovoltaic panels, a 1st Generation Polycristalline 5kW array on a 5kW MPPT Inverter and a 4.6kW Thin Film CIGS array on a second 5 kW MPPT Inverter. The CGIS array constitutes the Illawarra Flame's Photovoltaic-Thermal (PVT) system: a number of thin-film PV panels mounted on a steel sheet flashing that is fixed to the top of an existing sheet metal roof profile (Figure 1). This system creates a cavity underneath the steel flashing through which the working fluid, air, can flow and exchange heat with the PV panel. The advantages of a PVT system rather than a PV system include an increase in the efficiency of the PV panels by reducing and regulating their temperature and the possibility to extract or release heat for heating or cooling purposes. This process increases the total energy extracted from the solar system, therefore improving the overall efficiency of the system.

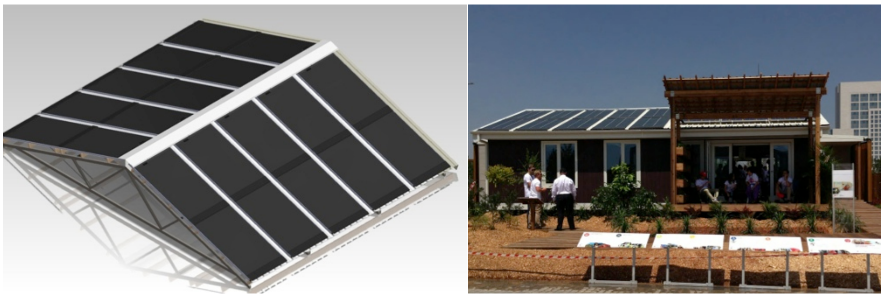

Figure 1 Solar Decathlon House PVT system

The performance of the Illawarra Flame PVT system is enhanced by coupling it with a PCM thermal energy storage system. By using this thermal storage system it is possible to phase-shift the thermal generation so that thermal energy may be released at times when generation is not possible. The system can be used both for heating and cooling. Further cooling of the ambient air can be achieved in the PVT system, since during clear nights, it radiates heat to the sky.

The Illawarra Flame BMS is based on an off-the-shelf residential control system, Clipsal C-Bus. This control system manages different systems implemented on the building, including the solar assisted HVAC system, electrical generation and distribution and automated high level windows for natural ventilation. To achieve this goal, readings from a Davis Vantage Pro 2 weather station, integrated in the control system, support logic decisions and inform users through graphic interfaces. (Figure 2)

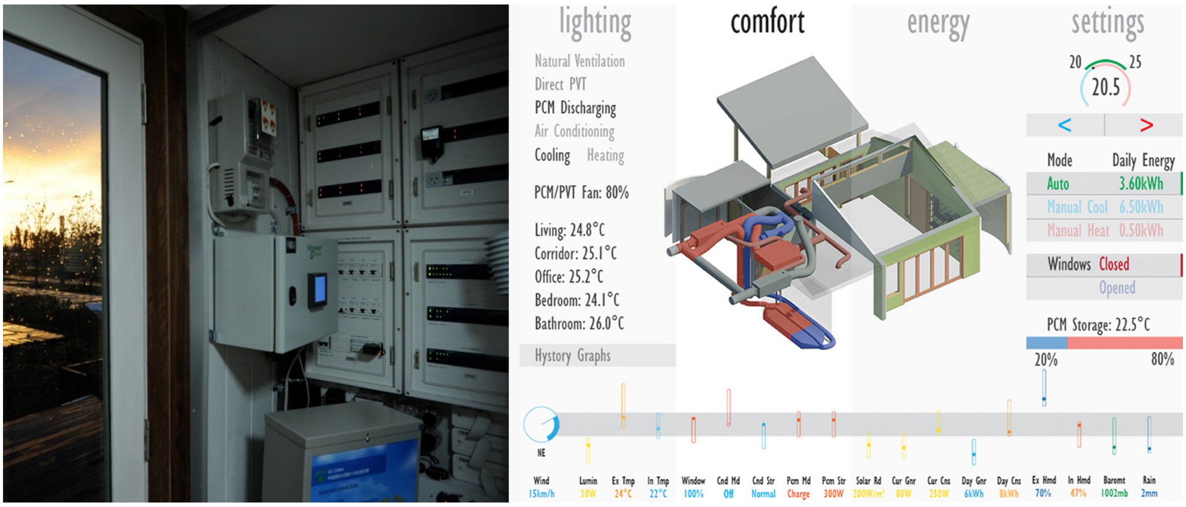

Figure 2 Solar Decathlon House BMS and SD house interface

Managing and displaying information are key features of BMS systems. One of the objectives of the Illawarra flame BMS is to let households be aware of the house performance, educating them on the different aspects of managing energy in the house. The user can easily access the consumption of each electrical subdistribution circuit and try to target a reduction of the most energy consuming appliances. One can see how much energy can be harvested by the solar assisted HVAC system and which working mode the HVAC is operating at each time to maximise its efficiency.

Integrating the readings from the weather station, the BMS displays outdoor conditions and indoor performance. Therefore, users can take the best decision to guarantee comfort with the use of natural ventilation or reducing the energy associated to conditioning with the different mechanical systems. The interface botton part displays a gray strip that identifies the comfort zone or better conditions for each variable. The coloured bars indicate the variables interval in the previous 24 hours and a filled dot, inside these bars, expresses the current measurement, facilitating quick readings by lay people.

The BMS system controls on/off dampers, variable position dampers and variable speed fans, to set the system in the correct working mode. The system considers the generation and storage status with the house heating/cooling demands, optimising it to achieve the required thermal comfort with the maximum efficiency. The logic has been custom developed in Pascal language on the house C-Bus Pascal logic controller. A touch screen and a web supervisory engage the users in the systems performance displaying generation data of both arrays as well as thermal storage.

The Illawarra Flame house comfort conditions are maintained using the feedback reading from 5 independently calibrated temperature sensors. Due to the small size of the house, the average temperature of the conditioned space is used for decision-making. The individual temperatures are fed back to the user though the touchscreen, as well as the average one.

The comfort can be achieved using mechanical heating or cooling, using the different working modes of the Solar Assisted HVAC system or, every time outdoor conditions are favourable, using natural ventilation. In this case the BMS will open automatically the high level windows and advise the user to open the non-automated windows. Automatic opening of windows can be always be overridden by the user using the touchscreen or wall pushbuttons. Households can also define different temperature setpoints that overwrite the system Auto Mode. Predicted energy consumption is provided by each temperature user setpoint, who can compare with the prediction for the Auto Mode.

THE FLORIANOPOLIS HOUSE

The Florianopolis House is located in the south of Brazil, within an island, more than 50km long and around 20km wide. It is near a beach, which has few elevations and temperatures slightly lower than the interior of the island, ranging from 7,5°C and 31°C, with around 1600mm of annual rain precipitation, 85% of annual relative humidity and about 140 days of rain per year (Lamberts et. al, 2010). Rainwater is therefore an important resource to be highlighted. The rainwater falling into the pool, with bamboo trees on the background (Figure 3), is enjoyed in the living room and collected for water reuse. The pool amplifies changes on the cycles of nature, such as sunny or windy days.

Figure 3 Views of Florianopolis House from inside the lot and from the back.

Comfort inside the house is ensured by two main strategies: significant amount of thermal mass protected by insulation and shading devices as well as cross-ventilation in the direction of the region prevailing winds (North, Northeast and South). These strategies should be managed by the residents, to avoid opening the house in hours of extreme heat. On warmer days, upper windows are opened at night and, on cold days, closed windows let the warm sun in. The main facade, facing the pool is oriented N/NE, with large windows and doors that ensure ample lighting and sunlight in the colder months. Wooden panels on the upper balcony guarantee shading the rooms, providing more privacy to the bedrooms, when superimposed. The upper balcony provides protection to the hot sun during the summer, allowing it in to warm the colder days.

The BMS developed for the Florianopolis House is integrated with a Davis 6250 Vantage Vue weather station and an Internet weather forecast provider. Connected to different home sensors, it supports dweller awareness and their decisions. Some tasks are automated, however, the system most significant contribution is to provide a holistic comprehension of the house systems and the environment, building up users' concern to perfect house usage towards a more sustainable living.

Temperature sensors located in the living room on the lower floor, the top of the stairs, and the master suite show the temperature difference in these rooms and allow for comparison with the external temperature. (Figure 4) Different colours display the relationship between these four temperatures from dark blue (cooler) to red (warmer). The green circle displays humidity. A graph of the variation of the four temperatures (living room, roof, suite, and outdoors) allows checking of the performance of the house in the last 24 hours, confirming the adequacy of adopted strategies and data from the local weather station, associated with progressive variation of colours facilitates reading and comparison.

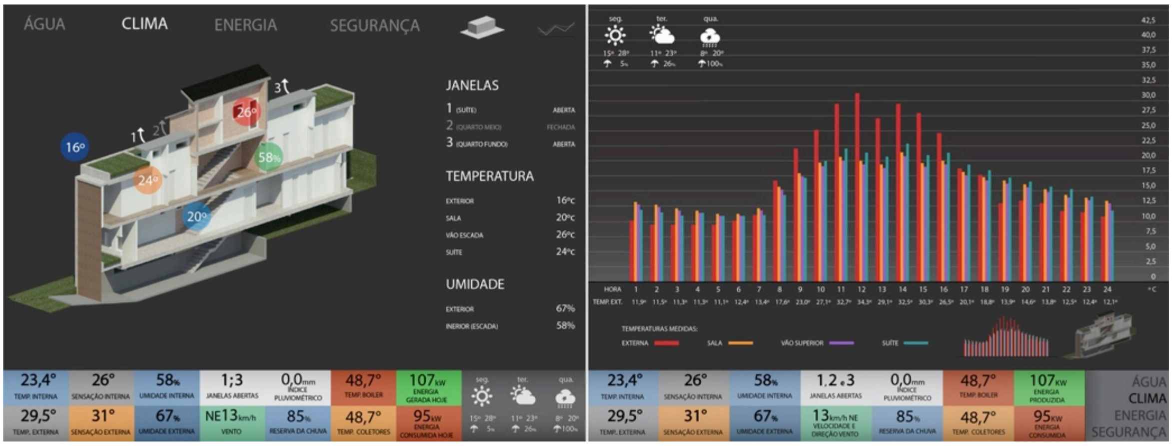

Figure 4 Screen for temperature and upper window control and bar graph.

With the association of temperature data from these sensors with information from the local weather station, such as speed and wind direction, one can plan a strategy for the next hours or days, with the support of the weather forecast. Three upper windows open above the roof, helping to extract the interior hot air. Those windows are motorized and controlled by the BMS. Therefore, it is possible to remotely open them. They close automatically on days with rain and strong southerly winds, to avoid water entering into the house. Combined with the other windows, they ensure cross-ventilation, which is particularly effective in such humid climate.

The three-floor height central volume, formally emphasized by the use of solid brick, facilitates the extraction of hot air from the ground floor. In warmer weather, ceiling fans in bedrooms alleviate the thermal sensation, without mechanical air conditioning devices. A house with a significant amount of thermal mass requires some strategy for managing its openings. They are not a direct response to the current conditions, similar to sailing boat that often take a lower speed direction that would prove to be more effective in a longer term. Therefore, the decision is not only based on the difference between interior and exterior temperature, but also a prediction of extreme higher or lower temperatures. Local information is associated with a three day weather forecast, allowing dwellers to plan strategies to ensure internal comfort within the house in the following hours or days. Data displayed through the graphic interface information would suggest the choice of windows to be opened or closed or the use of additional systems, such as the roof evaporative cooling or, in extreme conditions, the air-conditioning.

The bar graphs are aimed to support residents to learn with and about their house. The house systems become more transparent once the users find their location and performance, leading to more sustainable procedures and habits. The BMS and particularly the supervisory graphic interface are critical for this aim. The interface integrates numeric information, such as air temperature, with scalable vector graphics (svg). Therefore, one easily and quickly distinguishes temperature variation, translated into colour, in different areas of the house as well as outside temperature. The interface is optimally visualized on an iPad or a computer screen, although it can also be controlled through a smart phone. Data is organized in four main groups: energy, water, weather and security and background image changes also according to the menu item. Managing water and energy resources are also important aspects of the system, but will not be detailed in this paper.

The open source supervisory control and data acquisition (SCADA) system is a critical component for the Florianopolis House BMS. The open supervisory (SCADABR) has been developed at the Federal University of Santa Catarina for a broad range of uses. Choosing an open source tool was one of the research goals. A relevant objective of the BMS research project is to test sustainable management solutions for low-income housing. Reading information is critical to maximize house performance, adapted to the residents' needs and sensors' data increasingly adds complexity to the interface. Thus, data has to be organized by hierarchy importance relating to different dwellers understandings.

CONCLUSION

This paper does not aim to provide a result of the two systems' impact evaluation on households or on energy use. One of the reasons is that the systems presented have just been implemented. In addition to that, the two houses are not targeted for regular families. The Illawarra Flame House was erected at the Wollongong University campus. The house will most probably be used by different guests. The other one is the home of one of the researchers, who cannot represent a regular use of a house. Therefore, the authors depart from an analogy of sailing race instruments to demonstrate the potential of automation systems on the house performance and, more important, on households' behavior. Similarly to the most important sailing races, such as the America's Cup, the Solar Decathlon competition has provided relevant and innovative experiments on home automation oriented to sustainable house performance. Our argument is that if research on America's Cup instruments soon became available to other sailing boats, the systems developed to the Solar Decathlon houses could, and should, be accessible to a great number of home owners. The two systems illustrated in this paper convey a further development of Solar Decathlon research. The system accomplished for the Chinese Solar Decathlon continued to be improved after the competition and is presented in its current stage. The system for the Florianopolis House departed from the system of the Brazilian Solar Decahtlon 2012 house, embodying its concept and some of its features. Instead of hiding the complexities of all the houses' systems, both of them attempt to present and understanding of the house functioning, engaging and challenging the users for a better performance. We argue that home automation systems have a relevant potential that is not explored by the market. In addition to reduce the effort to perform some of the daily dwellers' tasks, these systems are noteworthy tools for more sustainable home behavior.

Although the BMS design of the two houses followed similar principles, they highlight their houses specificities and display both their houses and BMSs'sustainable features. The complexity of the Solar Decathlon house has offered increased possibilities for testing more innovative approaches. On the other side, the main contribution of the Florianopolis house BMS to engage users is through history graphs, data translated to colors and the 3D section renderings. Apprehending the impact of habit changes in the house performance is not an easy task and is critical to engage users. Sailors can check their instruments in order to evaluate a different sail regulation. Our houses have a much slower response and instant data from energy consumption, for example, does not directly translate the impact of changing an activity. Overall daily energy consumption, as well, displays several different circuits that may considerably vary during the day. Thus, history graphs with hourly consumption of two different days may facilitate the identification of the impact of an activity's change, comparing data from the current and the previous days. Different patterns of opening windows during two similar and consecutive days can present contrasting temperature results in the rooms. Similar history graphs with hourly temperature bars of different rooms are very educative about the house performance. Users can benefit from learning to better use their houses with a much more pleasant comfort outcome, reducing environmental impact. A good design has also a unity. A sustainable house requires sustainable households. Connecting the latter with the house unity should be a critical aim of BMSs.

The Solar Decathlon house's BMS presents some additional contributions. The comfort zone bar facilitates the readings of the house performance and climatic conditions. Usually, households do not directly identify comfort zones in their daily use of the house. Air conditioning temperatures, for example, are many times set up after climbing stairs when arriving home. The comfort bar is not effective for all variables, for some, it may be decisive. Temperature, humidity, wind direction and spped, and even luminosity should be influential. They are often ignored and can be quite misleading even for more sustainable contemporary households. The possibility to identify if these variables are within the comfort zone supports more sustainable dwellers' behaviour, as well as a confirmation of their observation of the influence of natural cycles in the house performance.

The Illawarra Flame House BMS introduces also an analogous tool of the target speed celebrated by high performance sailors. The system calculates the energy consumption in the next 24 hours for the Auto Mode, as well as set point changes for heating and cooling. Therefore, the Manual mode is not only based on the assumption that the user has of a comfortable condition. The system actually provides a benchmark of an optimal Automatic Mode condition using every house resource to reduce consumption. Therefore, changes provided by the users could be predicted and compared against the ideal Auto Mode. They have ultimately all information for reducing consumption changing temperature set points.

Sailing instruments do not reduce the connections between good sailors and natural environment. On the contrary, they support experienced sailors with a confirmation of their empirical observations of nature. Contemporary urban dwellers have diminished their connections to natural environment. Technologies developed over the last centuries have reduced the need to adapt their lives to natural cycles. Building standardization has also contributed to this tendency. Studies from primitive communities highlight these remarks. They have developed their homes and the way they inhabit them based on empirical observations. Their habits are directly associated to the building performance, particularly in cases of extreme climate conditions. Experienced sailors have not lost, throughout history, their ability to understand natural cycles. We have aimed, through this paper, to advocate that these systems have added precision and confirmation to sailors' observations and they could support similar connections that urban dwellers lack.

ACKNOWLEDGMENTS

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Adaptive comfort and control protocols for natural ventilation

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ABSTRACT

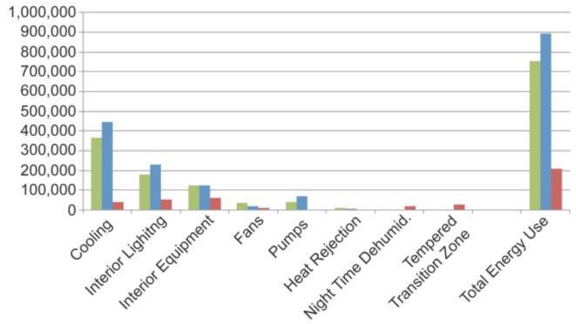
Recently there has been a shift in international standards towards adaptive thermal comfort. ASHRAE had formally incorporated adaptive comfort into ASHRAE Standard 55-2010. In adaptive comfort, the range of indoor temperatures perceived as comfortable drifts upwards in warm weather and downwards in cooler weather. This is especially true where the occupants have control over their thermal environment (for example, with clothing or operable windows) and when occupants are aware of the variable outdoor conditions.

This paper presents the ventilation control strategies used to provide adaptive comfort without air conditioning (compressive cooling) in a major retrofit for an office and classroom building on the University of Hawaii campus. The building retrofit is designed for cross-ventilation while taking care to acoustically isolate the spaces from each other and to dampen sound from outside. A supplementary fan system is designed and configured to complement the cross-ventilation strategy. The fan system is controlled to actively draw just enough air to provide adaptive comfort conditions when wind is calm. If the wind is sufficient, the controls sense the speed and direction and shut down the fans allowing cross ventilation to do the cooling. The fan controls sense the conditions inside, conditions outside the building, and weather conditions in the recent past.

INTRODUCTION

Kuykendall Hall at the University of Hawaii at Manoa (UHM) was constructed in 1964. It is made up of two building blocks connected by a bridged walkway. One block is a 56,000 sqft four story classroom building. The other block is a 20,000 sqft seven story office tower. Kuykendall Hall was originally built as a naturally ventilated building. Corrosion of window mechanisms and acoustic issues let to renovations in 1987 which made the entire building air conditioned. Due to the extreme high cost of energy in Hawaiian Islands, the university would like to transition many of the buildings on campus to be not air-conditioned or only partially conditioned. Kuykendall Hall was intended to be a pilot project in the pursuit of this strategy. After an analysis of different strategies, UHM chose to pursue an overall design that emphasizes natural ventilation and ceiling fans for cooling and comfort. Extensive computer modeling and physical modeling were done as part of this process. The modeling strategies had two objectives here. One was to model in an explorative manner so as to arrive at the design solution. The second was to analyze the design to understand the energy implications. EnergyPlus version 6 was used to simulate all zones of the building to understand the thermal and comfort implications on a detailed hourly basis for the whole year. Eppy - a scripting language for EnergyPlus (Philip, Tran and Tanjuatco 2011) was used to automate this process

Since the performance of ventilation was critical to the success of the project, a boundary layer wind tunnel testing was used to explore the design alternatives. We tested a massing model that included the site context within about 600 ft. of the building, and detailed models to study air flow within specific areas of the building. Models were placed on the wind tunnel turntable and tested under 9 different wind directions. The results of this study were presented at the 2014 AHSHRAE/IBPSA-USA Building Simulation Conference (Philip, S., Shameson, A., Brown, N., Loisos, G., Ubbelohde, S., 2014). The modeling described in that paper predicted the energy saving illustrated in Figure 1a and 1b, but is silent on the control protocols needed to achieve those results. The present paper describes the design configuration and the control protocol for comfort

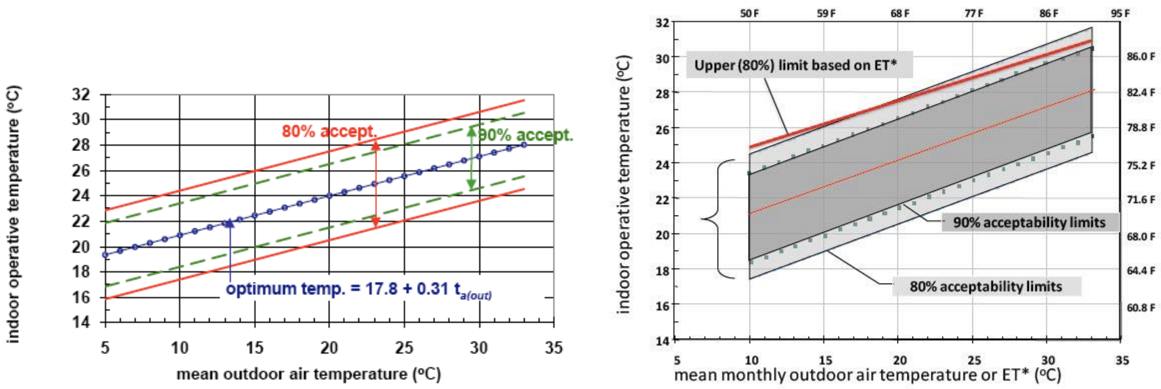


	Existing Building	Naturally Ventilated Option	Mixed Mode Option	Fully Air Conditioned Option
Total Annual Energy (kWh/yr)	893,386	393,928	563,772	771,861
% Savings over Existing	-	56%	37%	14%
Annual PV Prod. Est. (kWh/yr)	202,016	202,016	202,016	202,016
Net Annual Energy (kWh/yr)	691,370	191,912	361,756	569,845
% Savings over Existing	23%	79%	60%	36%

Figure 1: Expected Energy End Uses for the ASHRAE building, the existing building and the proposed buildings

ADAPTIVE COMFORT

The comfort chart depicted in Figure 2 (a) taken from ASHRAE Std 55-2010 ASHRAE 2010. The percentages in the diagram can be explained in the following manner: an indoor operative temperature falling within the 80% range should be regarded as acceptable or satisfactory to at least 80% of building occupants who are exposed to it, and the tighter 90% acceptable temperature range is likely to satisfy 90% of occupants.



(a) (b)

Figure 2: (a) The ASHRAE Std 55-2010 adaptive comfort standard as a function of prevailing outdoor temperature. $t_{a(out)}$ is the arithmetic average of the mean monthly minimum and maximum daily air temperatures for the month in question. (b) The ASHRAE 2010 adaptive comfort standard in naturally ventilated spaces showing the upper (80% acceptability) limit based on mean monthly ET*

ASHRAE's adaptive comfort was defined using the mean monthly dry bulb temperature ($t_{a(out)}$). In this project we have used the average of the last 15 days instead of monthly mean since we had access to realtime weather data. Note Figure 2(a) has OT (Operative Temperature) on the vertical axis and does not take humidity into account. In the original ASHRAE research project (RP-884) that led to the development of the adaptive comfort standard, mean outdoor effective temperature, ET*, was used to arrive at the comfort zone (de Dear and Brager 1998). ET* is defined as the temperature at 50% relative humidity which would cause the same sensible plus latent heat exchange from a person as would the actual environment. ET* values can be calculated using WinComf© (Fountain and Huizenga 1996). The modified figure is shown in Figure 2 (b)

When using ET*, the optimum indoor temperature is given as:
optimum indoor temperature = 18.9°C + 0.255 * outdoor_mean_ET* (1)

Acceptable temperature ranges around the optimum in naturally ventilated buildings were specified as ±3.5°C for 80% acceptability and ±2.5°C for 90% acceptability. This corresponds to the two acceptability deadbands shown in Figure 2 (a).

At the time this project was done in 2011, there was a proposed addendum to Std 55 to take in to account effect of airspeed on comfort. In this addendum, an increase in airspeed increases the acceptable operative temperature.

This project uses the upper 80% acceptable limit, with an airspeed of around 1 m/s, always available through ceiling fans, allowing us to increase the acceptable temperature by 2 degrees C.,

COMFORT THERMOSTAT

Traditionally thermostats have dry bulb temperature (DBT) setpoints. The traditional thermostat has a DBT sensor that checks if the room DBT is within the comfort range of the set points. In a cooling only model the thermostats tests if the room DBT is above the setpoint. If it is above the setpoint, action is taken to bring down the temperature in the room. Such a thermostat does not allow us to control for adaptive comfort, where the setpoint may change each day

So a comfort thermostat was designed to respond to adaptive comfort. The comfort thermostat we are using has a number of elements that are different from the standard thermostat. In a comfort thermostat, the metric used is operative temperature (OT) and not dry bulb temperature (DBT). OT is the average of mean radiant temperature (MRT) and DBT. In the standard thermostat, the setpoint rarely changes. In contrast the comfort thermostat sets the setpoint based on the temperature of the last 15 days. This takes into account the acclimatization of the body to the season. The setpoint for any particular day is calculated in the following manner:

- out_ET* = average of the ET* of the previous 15 days (2)
- optimum indoor temperature = 18.9°C + 0.255 * outdoor_mean_ET* (same as 2)
- 80% accept = optimum indoor temperature + 3.5°C (3)
- ceiling fan (1m/s air speed) = + 2°C (4)
- Thermostat setpoint = optimum indoor temperature + 3.5°C + 2°C (6)

If the OT is above the thermostat setpoint, steps have to be taken to bring the conditions back to comfort. The following sections describe the logic of how this is done.

CONTROL PROTOCOL

Objective: to keep the Operative Temperature (OT) in the comfort range.

Since the site is in Hawaii, we are primarily looking at the cooling to achieve comfort. Whenever the OT is outside the comfort range, the control protocol should take action to bring it back within the comfort range.

- Whenever the conditions are not comfortable within the space, the occupants can operate the windows to become comfortable.
- If the Operative Temperature (OT) is too high, open windows will allow natural ventilation to cool the space
- If the Operative Temperature (OT) is too low, the windows can be closed to keep the cold air out. This is less of an issue in Hawaii's climate
- If the windows are open and there is no wind, there will not be enough air changes (Air Changes per Hour **-** ACH) to cool the occupants.

- Now the forced air fans will start up and provide the needed ACH
- The volume of forced air increases until comfort conditions are reached.
- The control protocol watches for wind conditions. If the wind picks up again, with sufficient velocity to bring about comfort, the forced air fans will shut down.
- If the control protocol is not watching for wind, the forced air fans will simply shut down after running for some time. When the conditions reach a point of discomfort, the fans will start up again will start up again.

CLASSROOM VENTILATION

The ventilation in the classrooms is either through cross-ventilation or through forced ventilation. When the air changes are happening through cross-ventilation, the forced ventilation part of the system is shut down. Similarly when the forced ventilation is running, the cross-ventilation part of the system is closed down. The geometry of the building forced the adoption of this strategy where the building is in either one mode or the other.

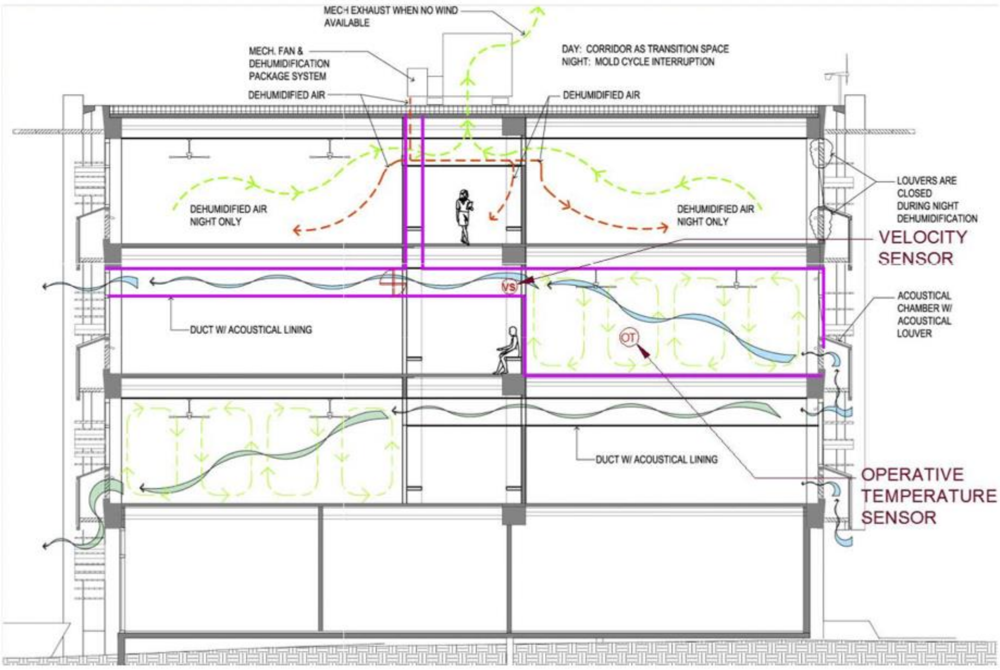


Figure 3 Configuration for natural ventilation and forced ventilation in classrooms

Configuration for natural ventilation: The classroom building has a double loaded corridor layout with classrooms on two sides of a central corridor. This makes it difficult to get cross-ventilation since only one side of each classroom is exposed to the outside. The proposed solution is to let outside air come in through a louvered sound attenuation box beneath the window and allow it to leave the classroom via a duct that runs over the opposing classroom and out the other side of the building. The air could flow in either direction. This is illustrated in Figure 3 above. There is a velocity sensor in the duct. Readings from this air velocity sensor can let us calculate the Air Changes (ACH) in the room. There is a damper in the duct that can completely close the duct, when the system switches to forced ventilation. In Figure 3, the middle floor illustrates the air flowing in one direction and the lower floor shows the air flowing in the other direction.

Configuration for forced ventilation: When there is insufficient wind to bring comfort through air changes, the cross-ventilation is shut down and forced ventilation starts up. During forced ventilation, the inlet air comes in through the sound attenuation box, below the window. The outlet air leaves through a duct at the opposite end of the room, that leads to a rooftop VAV fan. This is illustrated in the top floor in Figure 3. The outlet duct is the forced air duct. There is a damper in this duct that will be open during forced ventilation and will close when when the space is in cross-ventilation mode. This damper can also modulate it's position, so to vary the flow of air**.** Multiple ducts from multiple classrooms lead to a single variable air volume (VAV) fan on the roof. Each duct has a variable air volume (VAV) damper. In effect, this is a standard VAV system working in the reverse direction. The air in the room enters the VAV dampers and exits the system through the fan. The dampers in each room will close and open in response to the operative thermostat in the space. The variable speed fan will change it's speed in response to the static pressure.

Protocol for natural ventilation

- the damper in the force air duct is completely closed
- The damper in the cross-ventilation duct is fully open
- Cross ventilation will come in through sound attenuation box and will exit through the cross ventilation duct. Or the air will move through in the reverse direction.

Protocol for forced ventilation

- the damper in the cross-ventilation duct is closed
- damper in the forced ventilation duct is partially or fully open
- The fan driven air will enter through the sound attenuation box, pass through the room and exit through the forced air duct, that leads to the rooftop fan

Control strategy for classrooms

Computer simulations in this project have shown that air changes in the space is critical in bringing about comfort conditions. The control protocol is built on this understanding that ACH in the space has to be estimated and modified if needed. To do this the ACH in the space has to be estimated under three conditions. The ACH has to be known 1) during natural ventilation. 2) during forced ventilation and 3) when the wind speed and wind the direction are known, the potential ACH from natural ventilation has to be estimated. It is done in the following manner:

1. ACH due to cross-ventilation. There is an air velocity sensor in the cross-ventilation duct. This duct is straight and long, so the readings are reliable and will allow us to calculate the ACH in the room. Let us call this "ACH_cross_vent"
2. ACH due to forced ventilation. This can be measured by an air velocity sensor in the forced air duct. It is possible that this duct is too short to get an effective reading from the sensor. In this case ACH can be calculated from the position of the VAV damper and the fan speed. Let us call this "ACH_forced_vent".
3. ACH_lookup_table. Detailed wind tunnel studies were done and a lookup table was developed to where for any wind speed and direction, we can lookup the ACH in a classroom. So based on data from the weather station, we can lookup the potential ACH_forced_vent in any classroom. (Once the building is operational, we can fine tune the lookup table based on air velocity readings in the cross-ventilation duct and weather data.)

The most efficient state is when natural ventilation and the operative temperature (OT) of the room is less than the thermostat setpoint (T-setpoint). Here the damper in the cross-ventilation duct is fully open and the damper in the forced air duct is completely closed.

As long as the conditions in the space meet the setpoint, this state will continue with cross-ventilation. If the OT within the space rise above the set point, the forced ventilation will start up with the steps listed in the sub-section “protocol for forced ventilation”. Figure 4 shows the logic of this.

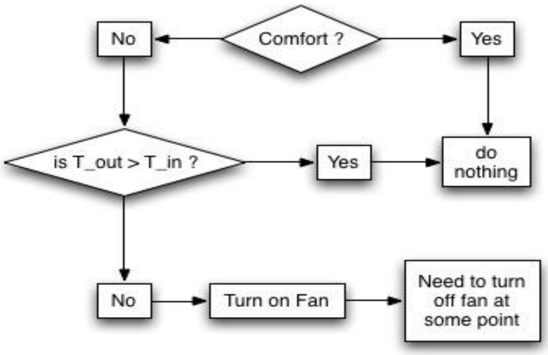
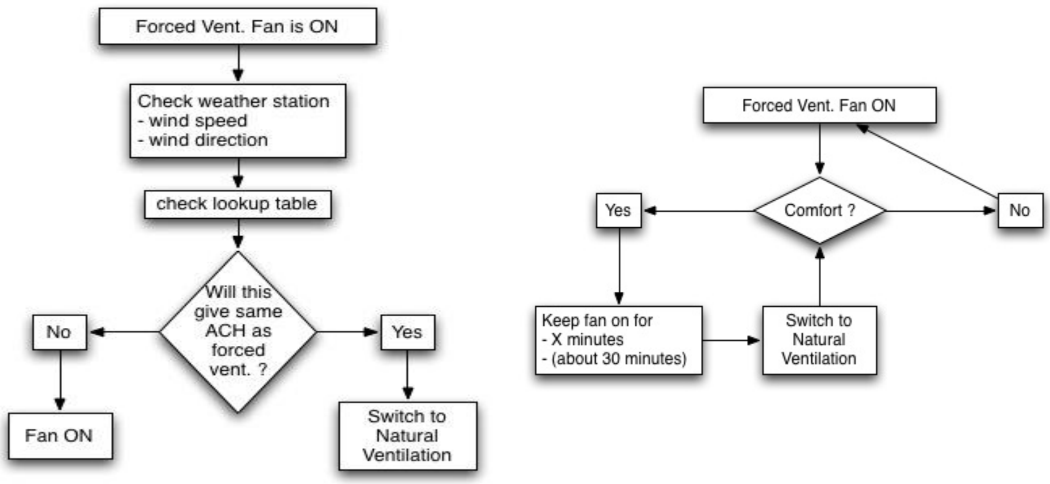


Figure 4 Turn fan on in classroom



(a) Switchback Strategy 1 (b) Switchback Strategy 2

Figure 5

One the forced ventilation starts up, there is need to switchback to natural ventilation whenever natural ventilation can meet the comfort needs. The control protocol needs to know when to do the switchback. There are two strategies for this. The first one called "switchback strategy 1" In the "switchback strategy 1" the control protocol will retrieve the air speed and wind direction from the weather station. Using this air speed and wind direction the ACH_lookup_table will return the resultant ACH due to cross ventilation. Now if ACH_cross_vent is greater than ACH_forced_vent, there is sufficient wind to cool the space by natural ventialtion. So the system will switch over to natural ventilation. Otherwise it will stay with forced ventilation. Figure 5 (a) shows this control logic.

Switchback strategy 2 has a simple logic. Continue with powered ventilation for some time after the set-point is reached. This extra time acts as a dead-band. After the waiting period, switch back to natural ventilation. Until the building is operational it is not clear which strategy will be more effective

Response to high outdoor temperature

If the outside temperature is too high during forced ventilation period, bringing a lot of hot air from outside will not contribute to comfort. Under such circumstances, the dampers should move to their minimum ACH position that will meet the indoor air quality.

OFFICE VENTILATION

The remodeled office has two corridors that run the entire length of the office building. Exploring design alternatives in the wind tunnel, it was discovered that if the long corridors were closed at one end and left open at the other end, all the rooms got sufficient ventilation. The prevailing wind would come into the corridor and pressurize the corridor. This pressurization would push the air into all offices adjacent to the corridor. If the wind came from the other direction, the corridor would get de-pressurized and it would draw air from the offices, allowing a flow in the opposite direction.

All the offices are connected to an exhaust fan system that can vented by forced ventilation if the natural ventilation is insufficient. The forced ventilation system is similar to that of the classroom. It works like a standard VAV system operating in reverse. The air in the room enters the VAV dampers and exists the system through the fan. As the dampers close or open, the variable speed fan will change it's speed in response to the static pressure.

The office ventilation strategy is fundamentally different from that of the classroom. In the classrooms either the forced ventilation is on or the natural ventilation is on. In the office, the natural ventilation can be on with the forced ventilation assisting it.

Office control strategy

- if the Operative temperature (OT) is greater than the thermostat setpoint (T_setpoint) the VAV exhaust fans come on
- in case of high outdoor temperature, office forced ventilation strategy follows the same rules as the classrooms, in that the forced ventilation volume drops down to the minimum ACH needed for indoor air quality

Switch off strategy in office

Since the forced ventilation fans in the office simple assist the natural ventilation, the idea of switching back and forth between forced and natural ventilation does not arise. Once the setpoint is reached, the forced air fans continue to operate for a certain time period. This extra time period acts like a dead band. Then the forced ventilation fans switch off

CONCLUSION

The standard way the controls are designed is to use a mechanical system to actively bring about comfort. This is done by the mechanical system keeping the temperature of the space below the setpoint. In a sense the standard control protocol is very simple. In designing the control protocol for a passively conditioned building through adaptive comfort, we are breaking new ground. We cannot be sure that system will work as designed and have to be ready to respond to unplanned behavior of the system. The building has been extensively modeled and the design calls for monitoring of all critical sensor points in the model. Thus we can observe the building in realtime and tune the control protocol in response to actual behavior. We also troubleshoot any aspects that are misconfigured. The project is awaiting funding approval from the state legislature. Once the retrofit is finished, we should have a more complete understanding of effectiveness of this control protocol.

ACKNOWLEDGMENTS

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- Cindy Regnier of Lawrence Berkeley National Laboratory for administering this project and keeping it on track.

NOMENCLATURES

ACH - Air Changes per Hour

ACH_Lookup_Table – See subsection: Control Strategy for classrooms", 3rd item on numbered list

ACH_cross_vent - ACH through cross ventilation

ACH_forced_vent - ACH through forced ventilation

DBT - Dry Bulb Temperature

MRT - Mean Radiant Temperature

OT - Operative temperature

RH - Relative Humidity

T_in – Temperature inside

T_out – temperature outside

T_setpoint – Thermostat setpoint. This will change every day on the comfort thermostat

UHM - University of Hawaii, Manoa

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Effective natural ventilation in modern apartment buildings

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ABSTRACT

This paper addresses the challenge of evaluating for natural ventilation in modern apartment buildings. A number of natural ventilation design rules of thumb from published literature are listed. Their incorporation into one code for Australia (the Residential Flat Design Code, or RFDC) and India (the National Building Code, or NBC), in relation to apartment buildings is examined. Practical limitations to converting these rules of thumb into effective natural ventilation systems for apartment building designs are discussed. Apartment designs in the moderate locations of Sydney, Australia and Bengaluru, India are also reviewed to assess their effectiveness for natural ventilation. Simulation analysis presented indicate large energy savings are possible if apartments are retrofitted/designed to the proposed code requirements and designs compliant with thumb rules are capable of delivering effective natural ventilation if users choose to operate the apartment in "free running mode" during times when the outside dry bulb temperatures lie in an appropriate band. The paper also discusses how sub-optimal design solutions, affluence and adaptation to more stringent thermal conditions can negate the potential for natural ventilation and calls for proactive efforts to maintain climate responsive design standards and education/policy to encourage the benefits of natural ventilation over airconditioning.

INTRODUCTION

Apartment buildings have become one of the most affordable residential building configurations in cities around the world. In many locations, they purport to incorporate natural ventilation design elements, usually based on the minimum mandatory requirements of applicable codes and standards. Anecdotally, an increasing number of such apartments are also being fitted with air-conditioning systems. These are either fitted by the builder (usually in developed countries like Australia, or upmarket offerings in developing countries like India), or retro-fitted by the occupant.

Easy access to air-conditioning brings with it the possibility of its increased use, even when conditions outside are conducive for natural ventilation to provide adequate thermal comfort. Therefore, the challenge faced in the design of modern apartment buildings is to ensure that the natural ventilation "system" is effective at providing thermal comfort at appropriate times, and to make the natural ventilation "mode" easily accessible to occupants.

Evaluating the effectiveness of natural ventilation in real building designs has always been difficult. The analyst is limited to using simplified equations developed for idealised room configurations, or complex energy simulation programs that can solve heat transfer and airflow network equations

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simultaneously in the same time step. Computational Fluid Dyamic (CFD) can solve for velocity and temperature gradients in discrete volumes, but these are limited to instances in time with specific boundary conditions. It requires significant processing power and time to run CFD analysis in time step increments so as to make a judgement of the effectiveness of system A against system B.

This paper came about because of a review (Thomas and Venkatesan, 2012) of the thumb rules for natural ventilation included as part of the Residential Flat Development Code (RFDC) carried out for the state government of NSW, Australia. The objective of the review for the RFDC was to develop a series of simple rules to allow a planner to approve a design on its merit. The method followed to develop these rules was as follows:

- review the body of currently available knowledge listing the attributes for effective natural ventilation
- turn them into a design calculation procedure simple enough to be carried out using hand calculations or a spreadsheet program, and
- document an application process that can be reviewed and accepted by a planning official

This approach has been implemented on apartment buildings in Sydney and Bengaluru. A two bedroom and a three bedroom apartment each from Sydney and Bengaluru have been selected for analysis. These represent the most common typology for Sydney and upmarket developments for Bengaluru.

PROCEDURE FOR EVALUATING POTENTIAL FOR EFFECTIVE NATURAL VENTILATION

The procedure devised and proposed to evaluate an apartment design for its potential for effective natural ventilation for the RFDC was based on common rules of thumb found in existing literature (Lechner, 2001). They include the following:

- The ratio of room depth (W) to floor-to-ceiling height is to be W< 5H for *cross ventilated rooms*; however for a standard ceiling height of 2.7m, the room depth may be extended to 15m when other conditions are met.
- The ratio of room depth (W) to floor-to-ceiling height is to be W< 2H for *single sided rooms*; however for a standard ceiling height of 2.7m, the room depth may be extended to 6m for living spaces. The ratio of room depth (W) to floor-to-ceiling height can be increased to 2.5H for rooms designed to have single sided ventilation when stack ventilation can be induced by providing a 1.5m height separation between inlet and outlet sections of the window.
- The *Effective Openable Area* for windows is at least 5% of the total floor area. Effective openable area of the window is defined as the area of the window that can take part in providing natural ventilation to achieve occupant comfort. It considers the portion of the window that is openable. Window openable area is reduced by 50% when insect screens are fitted. In the case of a full height sliding door, the openable area is reduced, in elevation, when it is within 2m of a solid balustrade.
- Windows are located so they are equally distributed on windward and leeward sides of the building. Windows on the leeward side (or "outlet" windows) may be allowed to be slightly larger than on the windward (or "inlet" windows) side of the building thereby utilising air pressure to draw air through the apartment.

Similar guidelines are found in the proposed draft for the new Part 11 of the National Building Code of India (NBC), (BIS, 2012) on Sustainability. It proposes the following criteria:

- Naturally ventilated building should take advantage of predominant wind, and enhance stack ventilation by providing low level inlets and high outlets
- Floor depths of more than 15m are difficult to naturally ventilate
- The total area of openings (inlet and outlet) should be 20 to 30 percent of floor area

The NBC does not distinguish between single sided and cross ventilation. To our knowledge, none of the building codes in either country provide explicit recommendations for mixed mode operation, which is crucial to realizing the potential of thermal comfort with reduced energy use.

CLIMATE ANALYSIS FOR BENGALURU AND SYDNEY

Bengaluru, India has always been regarded as the "garden city" with a temperate climate, being situated on the Deccan Plateau at a height of approximately 914m above sea level. Sydney, Australia is also well known for its mild climate, and is at sea level on the south eastern coast of Australia.

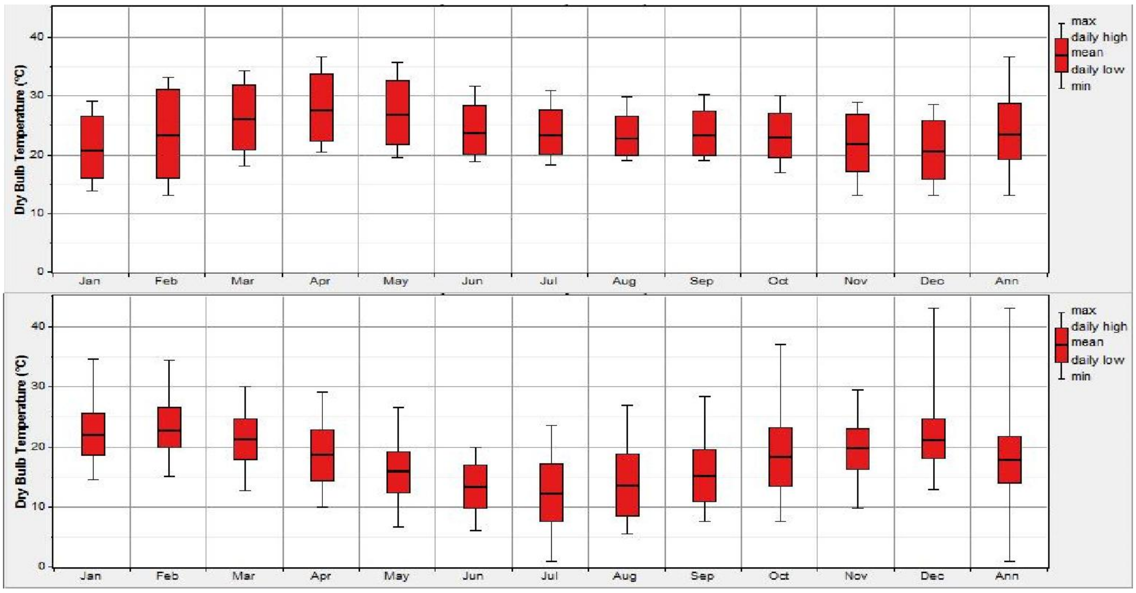

Figure-1: Temperature ranges for Bengaluru (top) and Sydney (below)

An analysis of the range of dry bulb temperatures for the IWEC reference weather files for Bengaluru and Sydney is shown in Figure-1 (and later in Table-1), and clearly shows the reversal of seasons due to the two cities being located on the north and south hemispheres on Earth. Figure-1 also reveals the variability of temperatures between the two cities. There are only small differences between the daily average mean high (or low) and the maximum recorded high (or low) temperatures for any one month (ie., the distance between the box and whisker) for Bengaluru, but the data for Sydney shows large variations between the box and whisker for each month. This effect is most clearly seen in the Sydney data for the months of October and December.

While there are many ways to analyse climate data in a comparative manner, the significance for this study is to determine the approximate number of hours when the outside dry bulb temperature falls within a nominated "comfort range". This would allow us to "bookend" the theoretical number of potential "discomfort" hours at each location. Regulation, and design skills could then be focused on reducing the number of discomfort hours by incorporating the principles of effective natural ventilation, thermal mass, shading, orientation etc.

It is difficult to find definitive regulatory information stipulating a "comfort range". In Australia, the NSW government does not provide any specific guidelines in the RFDC. The NatHERS (Nationwide House Energy Rating Scheme), referenced in the National Construction Code (ABCB 2013) uses a setpoint of 25.5°C for Sydney. Above this temperature an air-conditioner is assumed to cool residential spaces for the regulatory energy analysis. Heating setpoints in living spaces are to be maintained at 20°C during waking hours, ie, 7:00am to midnight, while bedroom spaces are allowed to drop to lower temperatures at night (http://nathers.gov.au/). For Bengaluru, the National Building Code (BIS 2003) of India does not seem to differentiate between residential and other buildings, and defines narrow temperature ranges for winter (21-23°C) and summer (23-26°C) for all building and climate types (Indraganti, 2010). While the appropriateness of these temperature ranges can be argued, they are sufficient for the purpose of bookending the potential "discomfort hours", based on ambient dry bulb temperature, for the two locations.

Inferences from Figure-1 and Table-1 provide important insights to the two climates. From Table-1, Bengaluru has less total "discomfort hours" (about 55% of the year), but they are divided almost equally into the too hot and too cold ends of the spectrum. Figure-1 indicates that highest temperatures will not be more than a few degrees higher than the daily average highs for that month, e.g, April. In contrast, only 4-6% of the year can be considered to be too hot in Sydney, but they can include some extreme days, note the 40°C day in December. However, about 75% of the year falls into the too cold category.

location	hours above 26C	hours below 21C	"discomfort" hours		hours above 26C	hours below 21C	"discomfort" hours
Bengaluru	2,265	2,520	4,785		26%	29%	55%
Sydney	367	6,178	6,545		4%	71%	75%
location	hours above 25.5C	hours below 20C	"discomfort" hours		hours above 25.5C	hours below 20C	"discomfort" hours
Sydney	482	6,008	6,490		6%	69%	74%

Table-1: Dry bulb temperatures above and below cooling and heating setpoint temperatures

Therefore, for Bengaluru, apartment design must be equally adept at dealing with overheating (comfort ventilation) and cold climate (passive solar gain, insulation, reducing infiltration). For Sydney, the focus should be on managing cold conditions. This means an emphasis on insulation requirements, which is addressed by the BASIX (Dept of Planning and Environment, 2013) for Sydney and mandatory building code (NCC) for the rest of Australia. However, the inferences from Figure-1 suggest that while there are few hours of over heating, they can be quite extreme when they do occur.

APARTMENTS SELECTED FOR ANALYSIS

Plans for a two bedroom apartment and a three bedroom apartment were selected at each location. The plans selected for analysis for this study reflect these differening views of apartment living in the two cities. Each of the apartments has been evaluated using the procedure discussed earlier. The selection of apartment plans for analysis is predisposed to layouts that were cross ventilated and of optimum depth. This is because we wanted to identify plan typologies that showed the potential for natural ventilation, where the limiting factor for mixed mode operation (and energy savings) were due to the potential, and attitude, for user control. The plans selected for Sydney were recommended as better design practice solutions in the RFDC technical document. These plans performed well when analysed for effective natural ventilation with respect to the proposed RFDC criteria (Thomas and Venkatesan, 2012). The plans selected for Bengaluru were procured from websites of prominent builders who marketed their layouts as being luxiourious upmarket/green. The Bengaluru apartment plans were tested against the proposed draft NBC Part 11 criteria.

Proposed RFDC Criteria (Sydney)	Ratio of room depth W to floor to ceiling height H is W<5H.	Effective openable area of window is atleast 5% of the total floor area	Inlet area equal to outlet area
2 Bed corner Apartment (Cross Ventilation)	Yes	Yes	No
3 Bed Apartment (Cross Ventilation)	Yes	Yes	No
Draft NBC Part 11 Criteria (Bengaluru)	**Apartment depth not greater than 15m**	**Opening Area of window is 20%-30% of the total floor area**	
2 Bed Apartment (Cross Ventilation)	Yes	Yes	
3 Bed Apartment (Cross Ventilation)	Yes	Yes	

Table-2: Application of procedure to determine potential for Effective Natural Ventilation

Table-2 indicates that all four apartment plans selected satisfy the building envelope design criteria for effective natural ventilation. Based on prior studies (Thomas and Venkatesan, 2012) the Sydney apartments (Figure-2), will therefore meet thermal comfort and minimum energy performance requirement for BASIX; and hence the energy use for air-conditioning will be low. Analysis from Table-2 indicates that users have the potential to effectively operate the apartments in a natural ventilation mode to further reduce energy consumption. Therefore, no further analysis has been carried out for these.

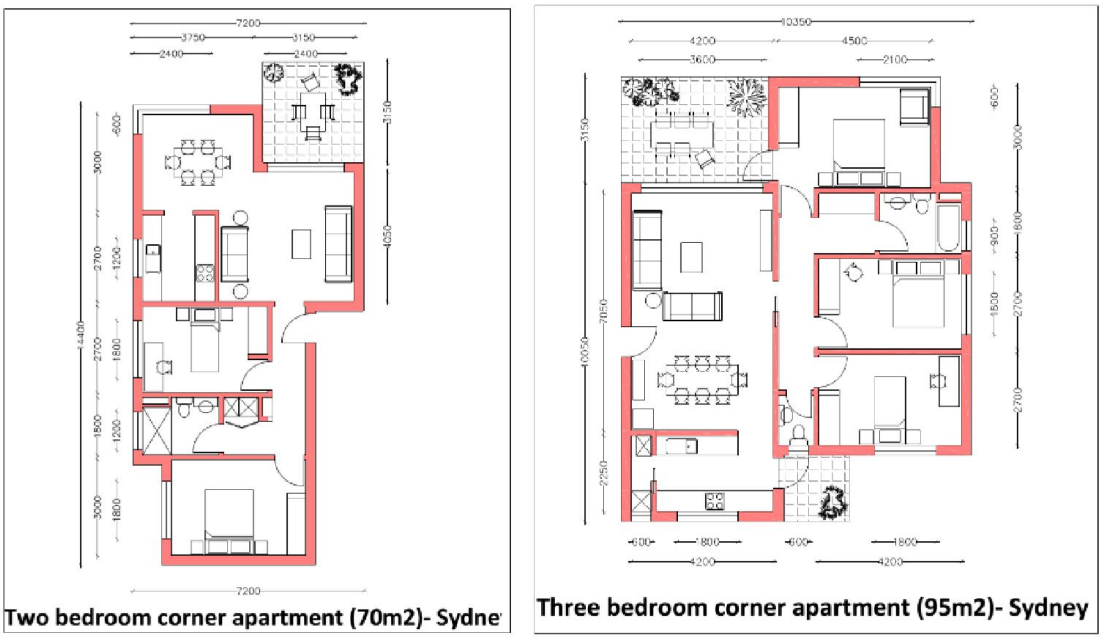

Figure-2: Floor plans of apartments analysed for Sydney, Australia

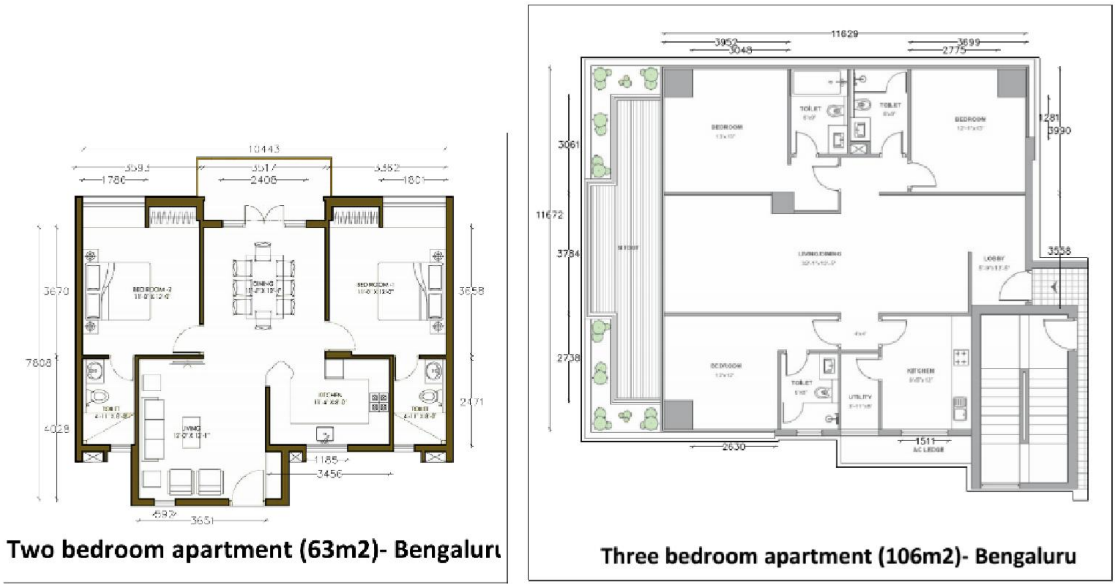

Figure-3: Floor plans of apartments analysed for Bengaluru, India

The three bedroom apartment in Bengaluru is proposed as a high rise block, as a part of a very large residential layout. The layout of the apartment shows good potential for cross ventilation capability. The apartments are being marketed as being fitted with split A/C units to living and all the bedrooms. They are also to be fitted with "clear float glass" with UPVC frames for all the windows. This last statement implies the use of single clear glass with no particular performance requirements.

An energy simulation model for the apartment was constructed using DesignBuilder/EnergyPlus that separated the living and sleeping zones. Floor and ceiling zones were modeled to be adiabatic, thus representing a typical middle floor apartment. Thermostat setpoints were set as previously discussed at 26°C for cooling and 21°C for heating. A design COP of 2.5 was used for cooling, and single zone split systems were modeled. Nominal internal loads were modeled, and these were identical for both runs. The annual energy consumption was predicted for two cases:

- for an uninsulated building envelope and clear single glass, and
- retrofitted with NBC levels of insulation and glazing performance requirements (external wall insulation of R2.0; SHGC=0.3-0.4 for WWR of 60-40%)

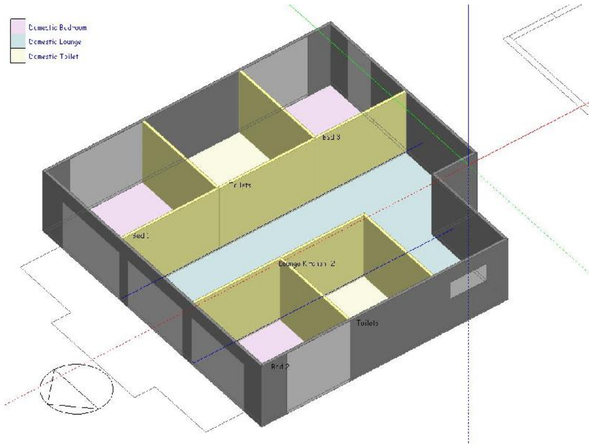

Figure-4: Representation of 3 bedroom apartment for energy simulation; floor plate has been divided into bedroom areas (night), lounge/kitchen area (day) and toilets (unconditioned)

The results predict minimal heating was required for both cases tested. Therefore only the cooling energy consumption was considered, and this dropped by 44% when the original design was remodeled with NBC recommendations (see Table-3). A significant portion of this reduction can be attributed to the improved glazing.

	Cooling Energy, KWh/m2-yr
3 Bed apartment with uninsulated building envelope and single clear glazing	40.8
3 Bed apartment retrofitted Insulation to fabric and Glazing performance as per Draft NBC section 11	22.7
reduction in cooling energy	44%

Table-3: Results of energy simulation for 3 bedroom apartment in Bengaluru

Figure 5 below indicates the predicted cooling load across the year in the bedroom (night time) and lounge/kitchen (day time) zones for the draft NBC compliant apartment if it resorted to airconditioning to maintain temperatures below the 26°C setpoint during occupied hours. While this suggests reliance on cooling beyond peak summer in daytime zones, field work in naturally ventilated buildings (Indraghati 2010, Manu etal 2014) suggests subcontinental occupants are tolerant to higher temperatures such as 28°C based on an adaptive model of comfort especially as increased air flow via ceiling fans can further ameliorate discomfort.

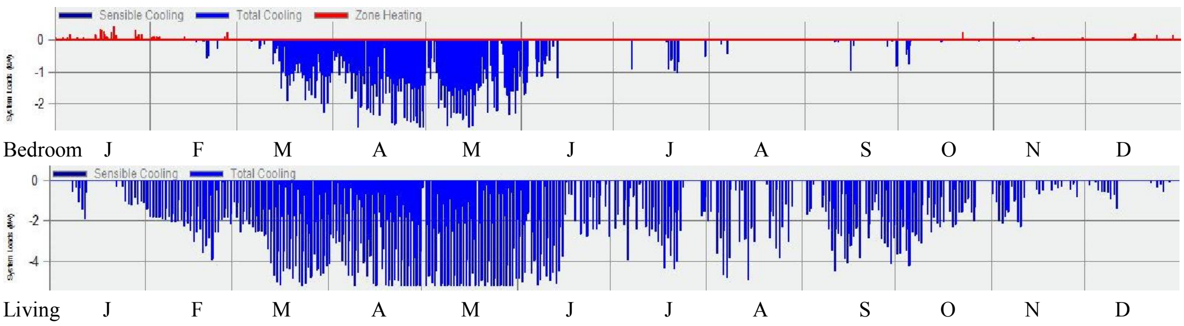

Figure-5: Predicted Cooling Load (kW) across the year for Bedroom and Living Zones (Bengaluru).

A final simulation run was carried out with the building allowed to operate in "free running mode" with controls that allowed windows to be open so that 30% of window area could take part in natural ventilation air exchange. The results indicate that this configuration allows the internal zone air temperatures to closely track the ambient outside temperatures (Figure-6, for both the Lounge Kitchen (Graph 1) and Bed 3 located in the south-east – the hottest corner (Graph 2). This confirms that effective natural ventilation is possible in the selected apartment design, when outdoor dry bulb temperatures are in the "comfort range".

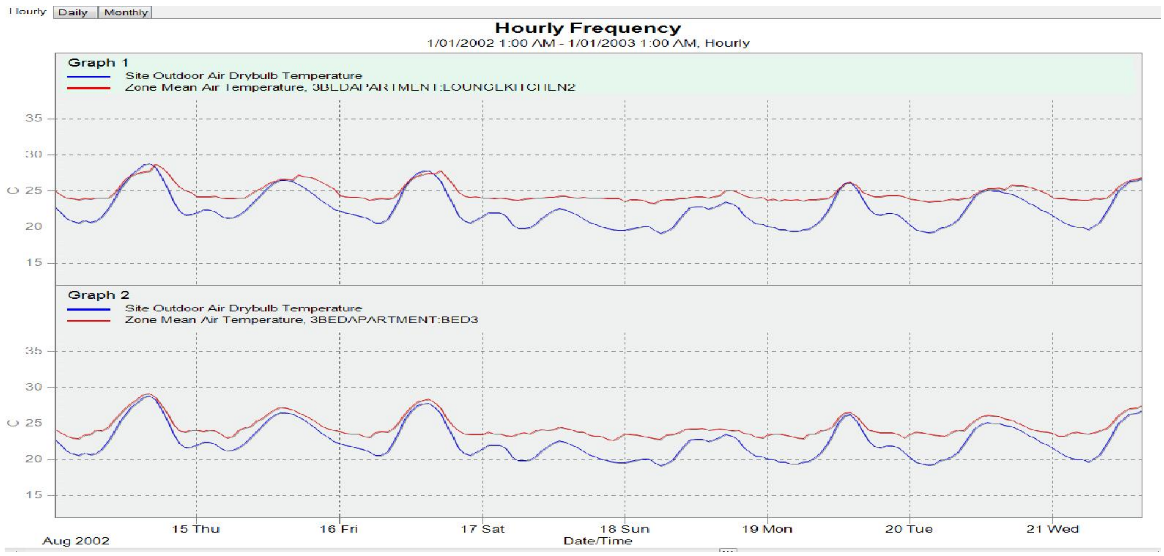

Figure-6: Outdoor dry bulb temperature and zone mean air temperature in free running mode for lounge/kitchen (Graph 1) and bedroom (Graph 2, Bed 3 in Figure 4), for 3 bedroom apartment in Bengaluru

BARRIERS TO EFFECTIVE NATURAL VENTILATION

In Australia, apartments are located in the Central Business District (CBD) areas of the metropolitan cities, or in areas where land is very expensive, along transport corridors (near train and bus routes) and also in the less affluent suburbs. In many instances, apartments may be regarded as a stepping stone towards the goal of an independent house and land package. One reason for this view is because real estate is a reasonably liquid asset in places like Sydney, where a sale transaction can be completed in a manner of weeks. Apartments also attract strong investor interest based on potential rental returns. Therefore, a significant proportion of apartment residents are rental tenants whose options to retrofit do not extend beyond installing a pedestal fan or an electric heater. Strata laws prohibit the owner from making alterations to the external common building elements like walls and windows and the installation of flooring and curtains/blinds are the prerogative of the owners. While energy costs are increasing steadily in Australia and can add considerable budget pain to the middle class, most new apartments come with reverse cycle DX type air-conditioning sstems pre-installed. This easy access to air-conditioning, coupled with design solutions that are less than perfect that may present barriers to the effective use of natural ventilation.

Three examples of such design solutions identified[1] in some Sydney apartment buildings are shown in Figure 7. They include deep, narrow floor plates which do not allow for effective cross ventilation (Figure 7 a), and deep set "snorkel" windows and deep "notch" corridors that effectively impede air exchange (Figure 7 b).

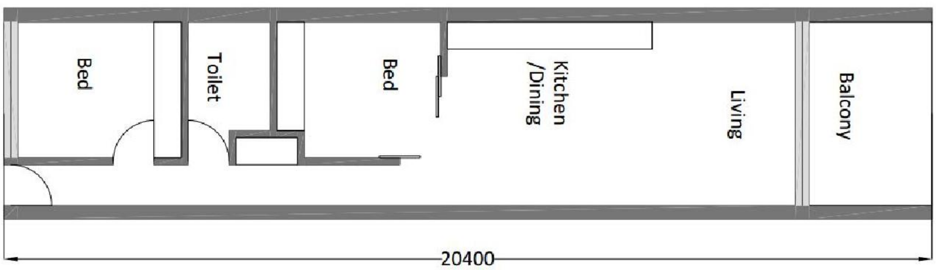

Figure-7a: Example of design solutions that reduce effectiveness of natural ventilation

[1] Zanardo, M. 2012, Personal discussion and review of apartment plans for Sydney

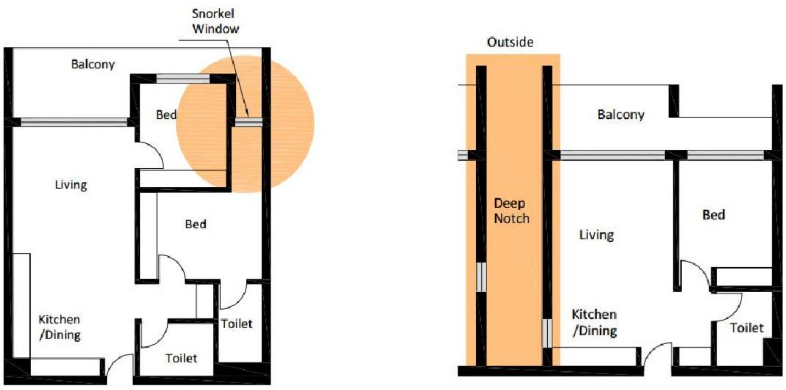

Figure-7b: Examples of design solutions that reduce effectiveness of natural ventilation

In places like Bengaluru, apartments are permanent homes, with many new developments offering high levels of luxury within the security of a gated community. Such luxury developments do have adequate spacing between apartment blocks to have an increased potential to operate in a naturally ventilated mode. However, such luxury apartments are also generally pre-fitted with A/C systems, and this easy access to air-conditioning diminishes the incentive for occupants to adapt to ambient conditions. This is exacerbated for the modern knowledge-worker, who aspires to live in such luxury apartments; regularly works in air-conditioned offices, and whose tolerance for temperatures beyond the closely controlled temperature band in the office drops with increasing adaptation to air-conditioning.

CONCLUSIONS

In a world where there is increasing evidence of rapid anthropogenic climate change, it is critically important that apartment designs provide easy access to the real potential for reduced CO2 emissions, so occupants can minimise their use of non-renewable energy use with little extra effort.

It is clear that the apartment designs selected for the two cities indicate that they pass the critical requirements to be able to provide Effective Natural Ventilation. The simulation analysis undertaken here predicts that

- large energy savings are possible if apartments are retrofitted/designed to the proposed NBC requirements of Part 11, and
- effective natural ventilation is possible if users choose to operate the apartment in "free running mode" during times when the outside dry bulb temperatures lie in an appropriate band

However, it is argued that this potential for effective natural ventilation, and energy efficient living can be easily subverted. As discussed in this paper, sub-optimal design solutions, affluence and adaptation to more stringent thermal conditions can negate the potential for natural ventilation even in the relatively mild climates such as Sydney and Bengalaru. This calls for proactive efforts to maintain climate responsive design standards and education/policy to encourage the benefits of natural ventilation over airconditioning.

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Session 3D : Tools and methods/ framework

PLEA2014: Day 1, Tuesday, December 16
16:05 - 17:45, Trust - Knowledge Consortium of Gujarat

Numerical Simulation of Passive Cooling Strategies for Urban Terraced Houses in Hot-Humid Climate of Malaysia

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ABSTRACT

The objective of this study was to determine energy-saving modifications through passive cooling to urban terraced houses in Malaysia. Effects of two strategies, i.e. complete natural ventilation (NV) strategy and partial air conditioning (AC) strategy, were simulated using TRNSYS and COMIS. The complete NV strategy relied fully on naturally ventilated condition in the whole house for achieving thermal comfort in the master bedroom while the partial AC strategy was aimed at reducing the cooling load in the air-conditioned master bedroom by applying passive cooling techniques to the whole house. The results revealed that indoor thermal comfort was achieved in complete NV strategy by applying multiple passive cooling techniques that prevent external heat on the outer building envelope and night ventilation, even under heated urban climatic conditions. In partial AC strategy reductions of about 39% to 56% in the sensible cooling load compared to the current scenario were obtained by using several techniques including night ventilating other spaces and insulating inner surfaces of the master bedroom.

INTRODUCTION

Energy savings are important in the global building sector due to concerns about energy security and effects of global warming. In hot developing regions such as Southeast Asia, cooling demand in residential buildings is a major concern since it is predicted to rise sharply in the coming decades in line with rapid urbanization and population and economic growth (Liu et al., 2010; Sivak, 2009). It can be seen widely in the region that brick-walled buildings are becoming a common construction for urban houses in recent years. In Malaysia, a nationwide census in 2010 showed that 85% of the existing urban houses used brick and another 5% used brick and plank for their outer walls (Department of Statistics Malaysia, 2012). Unlike traditional lightweight constructions, the high thermal mass building envelope of brick houses might be difficult to be cooled in the hot-humid climate. It has been reported in 2009 that space cooling in brick houses accounted for 29% of the annual household energy consumption on average in the city of Johor Bahru, Malaysia (Kubota et al., 2011). It is thus crucial to apply passive cooling strategies wherever possible to these urban houses for energy-saving.

Passive cooling encompasses techniques for solar and heat control, heat modulation and heat

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dissipation using naturally driven phenomena such as natural ventilation, radiative cooling, evaporative cooling and ground cooling (Santamouris and Kolokotsa, 2013). Passive cooling techniques have been studied in various climatic regions. However, few comprehensive studies were made outside moderate and hot-dry climates, including field monitoring and numerical modeling exercises with regard to existing Malaysian houses (Kubota et al., 2009; Mohd Isa et al., 2010; Sadafi et al., 2011). Some of the main climatic factors negatively affecting the efficiency of the different cooling approaches are high night ambient temperature, cloud cover, high humidity and insufficient wind speeds (Dimoudi, 1996). These conditions are usually prevalent in hot-humid climate. Due to dependency on climatic conditions, further local studies are required to predict effects of a passive cooling system before implementation.

The objective of this study is to determine energy-saving modifications through passive cooling to Malaysian urban houses. The target houses are terraced houses, which formed majority (42% as of 2010) of the existing urban housing stock (Department of Statistics Malaysia, 2012). This study analyses the effects of two passive cooling strategies, i.e. complete natural ventilation (NV) strategy and partial air conditioning (AC) strategy, on thermal comfort and cooling load, respectively, through numerical simulation using TRNSYS and COMIS programs.

METHODS

Description and Modeling of the Case Study Terraced House

One of the case study terraced houses from a previous field experiment (Kubota et al., 2009) was modeled in this simulation study. The selected terraced house represents typical modern terraced houses in terms of spatial design and building structures (Toe, 2013). The house measures 6.7 m by 13.1 m with a total floor area of 155 m^2, which is an average sized double-storey terraced house (Figure 1). Floor-to-ceiling height of rooms is 3.05 m. The total nett air volume of the whole house is 538 m^3; that of the master bedroom is 65 m^3. The building was oriented towards northwest, which means that the external façade of the master bedroom faces northwest. It was constructed of brick and concrete and had single glazing windows. The entire house was not insulated. Description of the constructional layers of the terraced house and their reference U-values in the computer model is given in Table 1.

The whole house was modeled as TRNSYS Type 56 'Multi-zone Building' in three dimensions using the TRNSYS 3D plug-in in Google SketchUp interface (Klein et al., 2012). The building model comprised 17 thermal zones with corresponding air flow zones in COMIS to represent each partitioned room or functional space including attic spaces. All protruding elements on the building facades and immediate surrounding objects, i.e. neighbouring houses, that might shade the studied house were also modeled in three dimensions. A time base of 1 h was set for the transfer function to represent the thermal

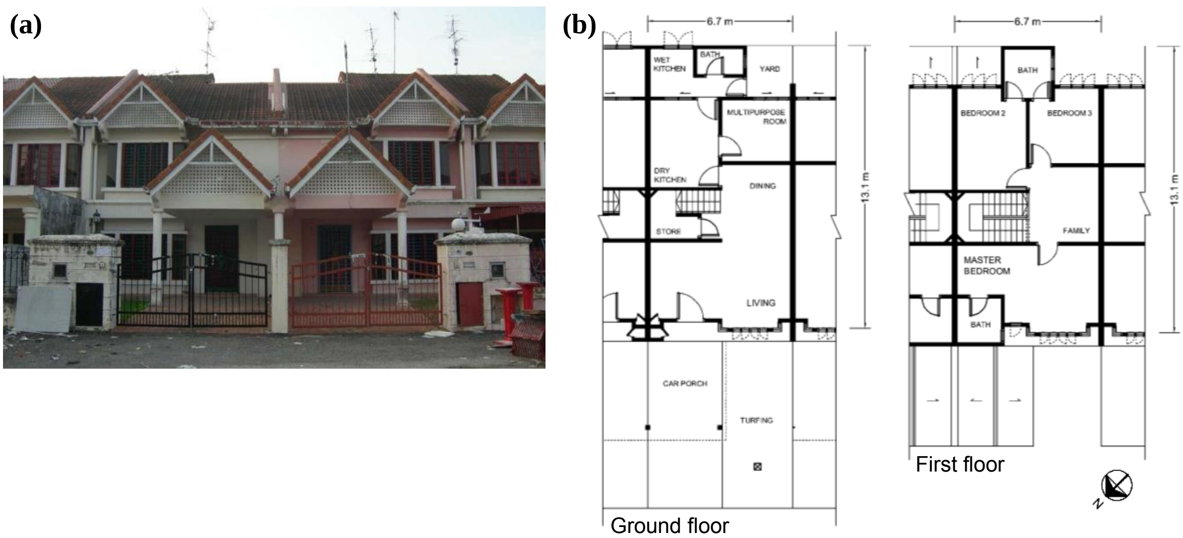

Figure 1 (a) Exterior view and (b) floor plans of the case study terraced house.

Table 1. Constructional Layers and Reference U-values of the Terraced House Model.

Building Element	**Constructional Layers**	**Reference U-value[a] (W/m²K)**
External and internal walls	20 mm thick cement plaster + 100 mm thick clay brick + 20 mm thick cement plaster	2.75
Party wall	20 mm thick cement plaster + 200 mm thick clay brick + 20 mm thick cement plaster	2.07
Ground floor	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + soil layer	3.75[b]
First floor (family and bedroom zones)	15 mm thick timber flooring + 15 mm thick cement screed + 100 mm thick concrete slab + 20 mm thick cement plaster	2.81
First floor (bath zones)	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + 20 mm thick cement plaster	3.29
Ceiling (master bedroom)	6 mm thick ceiling board	4.55
Ceiling (other zones)	3.2 mm thick ceiling board	5.54
Pitched roof	20 mm thick concrete roof tile + 25 mm thick timber batten + aluminium foil	2.67
Flat roof	22 mm thick cement screed + 100 mm thick concrete slab + 20 mm thick cement plaster	3.37
Window	6 mm thick single layer float glass	5.61

[a] Includes convective and radiative heat transfer coefficients of 7.7 W/m²K for inside surface and 25 W/m²K for outside surface.
[b] Excludes soil layer.

mass behavior of the brick walls. The party walls on both sides of the house were modeled as boundary walls with identical zone temperatures assumed on both sides of the walls. Meanwhile, the boundary condition for the ground floor was the constant soil temperature assumed to be the average air temperature at the site over the whole simulation period. Thermal properties of building materials and parameter/input values for air flows were obtained from Malaysian manufacturers or reference data to correspond with the local construction (Toe, 2013). Wind pressure coefficients were estimated using a parametrical model developed by Grosso (1992) known as CPCALC$^+$. Coupling between the TRNSYS and COMIS models were implemented via Type 157 in TRNSYS so that air flow rates per zone and zone air temperatures were iterated in each time step until the mass and energy balance per zone reached convergence.

Model Validation

Empirical validation of the terraced house model was performed using the above-mentioned field experiment data from June-August 2007 (Kubota et al., 2009). This study focuses on the results in the master bedroom because existing households used air conditioners mainly in master bedrooms (Kubota et al., 2009); the study interest is to reduce this cooling energy. Figure 2 shows temporal variations of the simulation results compared to the measurement data at 1.5 m height above floor in the master bedroom. Two ventilation conditions, i.e. night ventilation and daytime ventilation, are shown. Overall, the

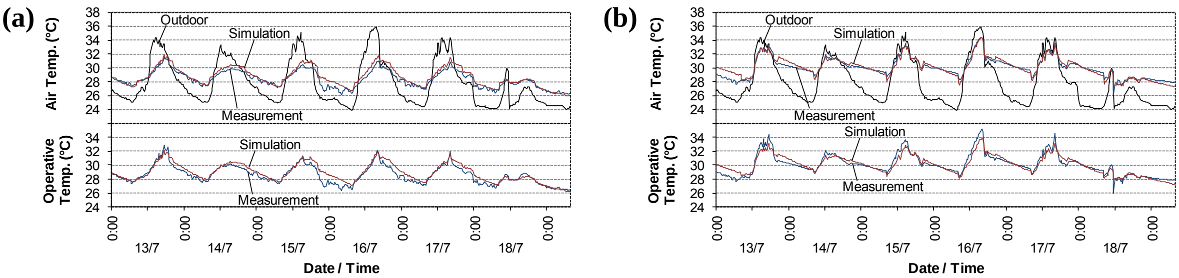

Figure 2 Temporal variations of the simulation and measurement data in the master bedroom in (a) night ventilation and (b) daytime ventilation conditions.

Table 2. Simulation Test Cases.

Technique	Test Conditions
Natural ventilation (open window period)	Night ventilation (20:00-8:00); daytime ventilation (8:00-20:00); no ventilation (0 h); full-day ventilation (24 h)
Forced ventilation	10 ACH or 30 ACH night (20:00-8:00) in master bedroom
Attic ventilation	10 ACH night (20:00-8:00) or 30 ACH full-day (24 h) in attic
Thermal insulation	Roof; ceiling; external wall – outside surface; external wall – inside surface; internal wall; party wall; floor (R-value: 4 m^2K/W)
Window shading	External shading; internal shading (Shading factor, SF: 0.75)
High reflectivity roof coating	Solar reflectance: 0.8, longwave emissivity: 0.9
Window glazing	Low-E glass (U-value: 2.54 W/m^2K, G-value: 0.44) or heat barrier film (U-value: 5.73 W/m^2K, G-value: 0.48)

validation results are satisfactory in terms of air and operative temperatures with root mean square errors (RMSE) of 0.31-0.55 °C and coefficients of determination (R^2) of 0.89-0.96.

Simulation Test Cases and Weather Conditions

Table 2 summarizes the simulation test cases of this study. The techniques were selected by considering their practicality to be applied to existing terraced houses through relatively simple building modification and/or behavioural adjustment. In particular, night ventilation is considered a potential passive cooling technique for brick houses while daytime ventilation emulates the window opening behavior of the majority of existing households (Kubota et al., 2009). The complete NV strategy relies fully on naturally ventilated condition in the whole house for achieving thermal comfort in the master bedroom. Meanwhile, the partial AC strategy attempts to reduce the cooling load in the master bedroom by applying passive cooling techniques to the whole house. It was assumed that air conditioning was used only in the master bedroom for nine hours per day (21:00-6:00) with a set temperature of 23 °C. This study deals with the sensible cooling load only. Internal heat gains from occupants (4 persons; seated at rest), lighting (5 W/m^2) and common household appliances were considered in all simulations. It is noted that infiltration rates in the master bedroom average 0.1 ACH when no ventilation was applied for both complete NV and partial AC strategies.

Weather conditions for the simulation were taken from an actual weather data set measured at the centre of a heat island in Johor Bahru, Malaysia to represent urban climate of typical terraced housing neighbourhoods (Kubota and Ossen, 2011). The geographical location is 1°29'19" N and 103°45'41" E at an elevation of 26 m above sea level. A wind velocity profile exponent of 0.25 was used to represent the urban location (Counihan, 1975). The simulation time step was set to coincide with the weather data at 10-minute intervals. The simulation was run using the above weather file for two whole months, i.e. January-February 2010. Subsequently, simulation results for a 10-day period of continuous typical fair weather days are analysed in this study. As shown in Figure 3, outdoor air temperature ranges from 25-36 °C while outdoor relative humidity ranges from 50-90% over the period. The analysis period begins several days after the simulation start time, thus allowing the model to acquire sufficient thermal history. Output files were generated and post-processed in Excel spreadsheets after the simulation.

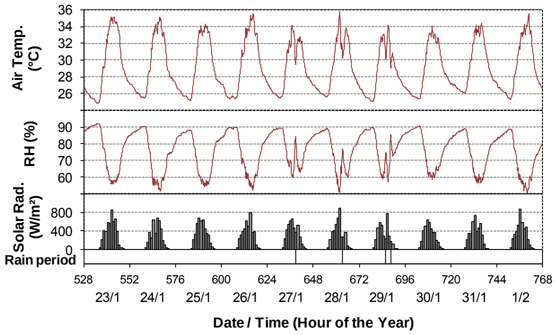

Figure 3 Temporal variations of weather data for the simulation analysis period.

RESULTS AND DISCUSSION

Complete Natural Ventilation Strategy

Figure 4 presents the simulated indoor air temperatures in the master bedroom for the four natural ventilation conditions that represent night ventilation, daytime ventilation, no ventilation and full-day ventilation. It is noted that temporal variations of indoor temperatures in each simulation have similar patterns over the 10-day analysis period. Thus, results are shown in statistical summaries for the whole period. As expected, night ventilation provides the lowest indoor air temperatures among the tested open window conditions (Figure 4). This is due to the nocturnal ventilative cooling through open windows and thermal mass effect of the cooled building structures that lowers the night-time and peak indoor temperatures of the following day. Daily maximum (95^{th} percentile) and minimum (5^{th} percentile) indoor air temperatures in night ventilated condition are 1.7 °C and 1.3 °C lower than those of daytime ventilation, respectively. Nevertheless, the daily minimum air temperature in the night ventiled room is still 2.7 °C higher than the outdoors.

Further passive cooling techniques are applied consecutively as shown in Figure 5 in addition to night ventilation and daytime ventilation, respectively. The most effective technique in reducing the daily maximum air temperature in night ventilated condition is roof insulation; the said temperature is decreased by 0.9 °C compared to applying night ventilation only (Figure 5a). Most of the solar heat gain in the master bedroom, which is on the first floor, probably comes through the roof due to its relatively large surface area and high noon solar altitude at the location. With less heat gain during the day and a cooler adjacent attic space for the whole day, the building structures maintain cooler and serve to reduce the minimum air temperature as well. Techniques that reduce solar radiation through roof into the building would be important. In fact, high reflectivity roof coating reduces the mean indoor air temperature most among all of the techniques in Figure 5a, i.e. by 0.6 °C. The high reflectivity coating probably improves nocturnal cooling additionally by virtue of the less heated roof surface on exposure to the sun and absence of thermal insulation at night. Nevertheless, all of the solar control techniques are

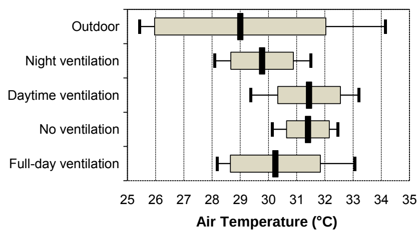

Figure 4 Statistical summary (5^{th} and 95^{th} percentiles, mean and ± one standard deviation) of simulated indoor air temperatures in different natural ventilation conditions for complete NV strategy.

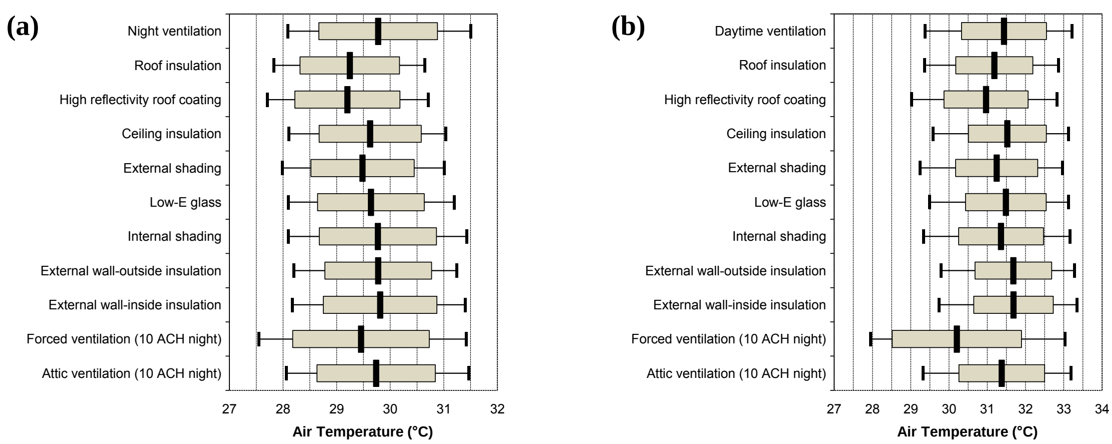

Figure 5 Statistical summary (5^{th} and 95^{th} percentiles, mean and ± one standard deviation) of simulated indoor air temperatures in (a) night ventilated and (b) daytime ventilated conditions with respective passive cooling techniques for complete NV strategy.

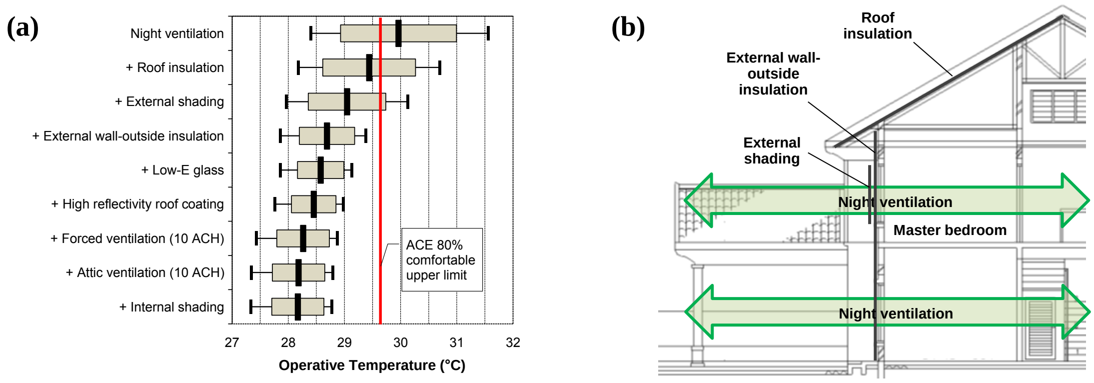

Figure 6 (a) Thermal comfort evaluation and (b) conceptual illustration of combined passive cooling techniques for complete NV strategy.

less effective in daytime ventilated condition compared to night ventilated condition (Figure 5b). The inflow of hot outdoor air through open windows during daytime increases the indoor air temperature and diminishes their cooling effects. On the other hand, forced ventilation with an air change rate of 10 ACH in the room at night lowers the daily minimum air temperatures most, i.e. by 0.6 °C and 1.4 °C in night ventilated and daytime ventilated conditions, respectively.

Figure 6a shows the simulated indoor operative temperatures for combinations of the most effective technique for each of the building elements. The techniques are applied accumulatively and step-by-step from more effective ones to less effective ones in night ventilated condition. The results are evaluated for thermal comfort using an adaptive comfort equation (ACE) for naturally ventilated buildings in hot-humid climates (Toe and Kubota, 2013). The 80% comfortable upper limits predicted using daily mean outdoor air temperatures of the analysis period average 29.6 °C. Figure 6a indicates that the daily maximum indoor operative temperature is reduced by 2.2 °C and meets the 80% comfortable upper limit when roof and external wall-outside surface insulation (R-value 4 m^2K/W), and external window shading (shading factor 0.75) are applied in addition to night ventilation under the heated urban climatic conditions. Alternatively, the comfort limit is also met by substituting the roof insulation with high reflectivity roof coating, though daily maximum temperature is higher in the latter. It is implied that introducing these four techniques to existing urban terraced houses may satisfy indoor thermal comfort in naturally ventilated condition on fair weather days (Figure 6b).

Partial Air Conditioning Strategy

Figure 7 shows the simulated sensible cooling loads in the air-conditioned master bedroom by considering different natural ventilation conditions for the master bedroom and other zones. The cooling load is 50.2 MJ/day when daytime ventilation is applied to the whole house (Case 1), which represents the current behaviour of most households. By applying night ventilation to the whole house except the master bedroom, the cooling load is reduced by about 5% even when the master bedroom is daytime ventilated (Case 5). Building structures that are cooled at night keep adjacent indoor temperature low and reduce the cooling load indirectly. The highest reduction in cooling load, i.e. 8%, is seen when the master bedroom receives no natural ventilation and other zones are night ventilated (Case 6).

Further passive cooling techniques are applied consecutively as shown in Figure 8 in addition to the ventilation conditions of Cases 1 and 6, respectively. For Case 1 the most effective technique in lowering

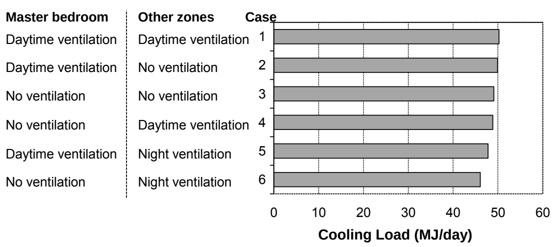

Figure 7 Simulated sensible cooling loads in different natural ventilation conditions for partial AC strategy.

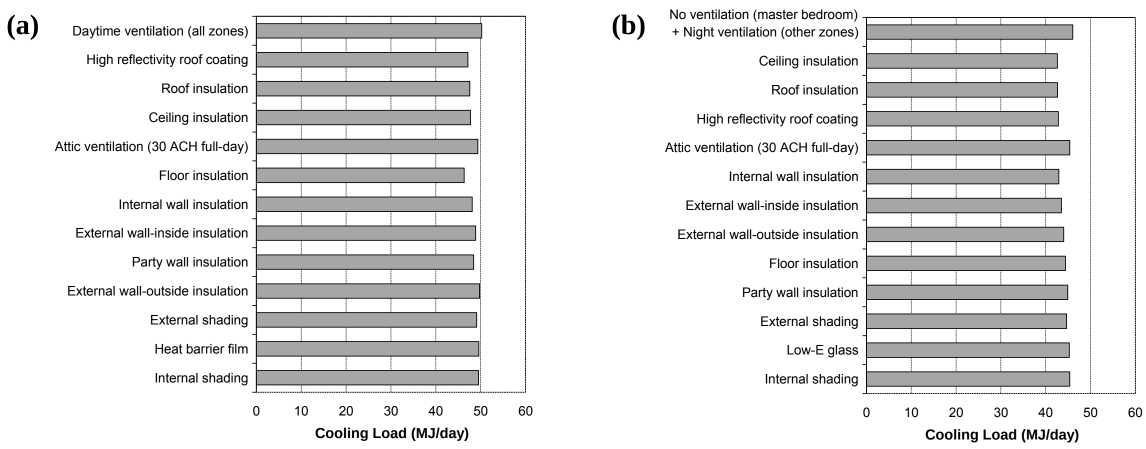

Figure 8 Simulated sensible cooling loads in ventilation conditions of (a) Case 1 and (b) Case 6 with respective passive cooling techniques for partial AC strategy.

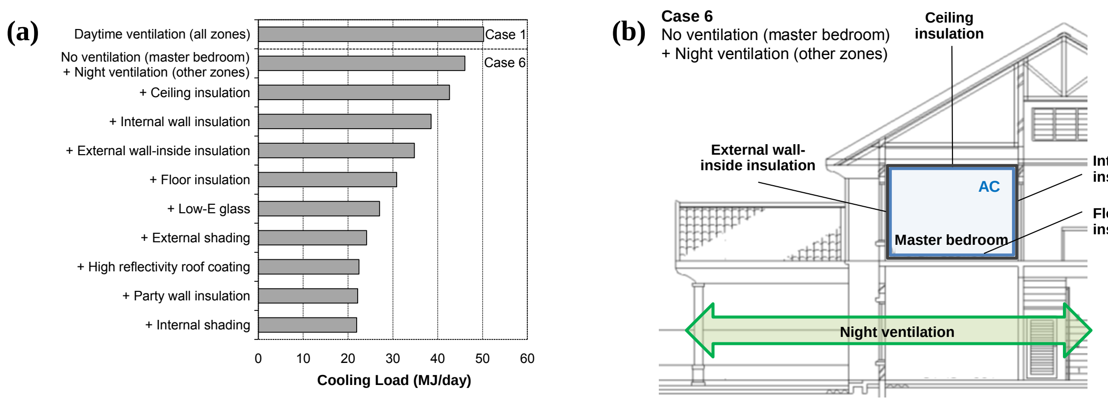

Figure 9 (a) Simulated sensible cooling loads and (b) conceptual illustration of combined passive cooling techniques for partial AC strategy.

the cooling load is floor insulation; the reduction is about 8% compared to the current condition (Figure 8a). Applying high reflectivity roof coating and roof or ceiling insulation give reductions of 6% and 5% each, respectively. For Case 6 ceiling insulation decreases the cooling load most by about 7%, followed by roof insulation and high reflectivity roof coating (Figure 8b). Besides, wall insulation is more effective on internal wall, followed by external wall-inside surface. Overall, all of the passive cooling techniques except floor insulation, party wall insulation and attic ventilation give greater reductions in the cooling load in Case 6 compared to Case 1, likely due to exclusion of hot outdoor air in closed window conditions during daytime.

Figure 9a presents the simulated sensible cooling loads for combinations of the most effective techniques in the ventilation condition of Case 6. As before, the techniques are applied accumulatively in step-by-step basis. Compared to the current condition (Case 1), the cooling load of the master bedroom is reduced by about 39% to 30.9 MJ/day when the ceiling, internal wall, external wall-inside surface and floor are insulated (R-value 4 m^2K/W) for Case 6 (Figure 9). The cooling load is lowered by 56% to 21.9 MJ/day when all of the techniques are used simultaneously, although the further reductions by high reflectivity roof coating, party wall insulation and internal shading are only about 3% or less each.

It is implied from the above simulation results that changing from daytime ventilation to night ventilation is fundamental to gain better effectiveness of other passive cooling techniques for both complete NV and partial AC strategies. Due to the intense solar heat gain through the roof, roof insulation for complete NV strategy and ceiling insulation for partial AC strategy provide the greatest cooling effects. In particular, for complete NV strategy techniques that prevent external heat on the outer building envelope are relatively effective to keep the indoors cool (Figure 6b). On the other hand, for partial AC strategy insulating the inner surfaces is relatively effective to reduce the cooling load (Figure 9b). Since the master bedroom is air-conditioned in this strategy, these techniques aid to prevent the mechanically cooled indoor air from being transferred outward.

CONCLUSIONS

The simulation results of a typical Malaysian terraced house reveal that indoor thermal comfort may be achieved in naturally ventilated condition by applying multiple passive cooling techniques that prevent external heat on the outer building envelope and night ventilation, even under heated urban climatic conditions. When air conditioning is used in the master bedroom, reductions of about 39% to 56% in the sensible cooling load compared to the current scenario can be reached by using several techniques including night ventilating other spaces and insulating inner surfaces of the master bedroom.

Further consideration of different building orientations, annual performance, cost-and-benefit effectiveness, and effects on indoor humidity as well as latent cooling load would be useful to realize their practical implementation in the urban terraced houses. Such modifications are expected to contribute largely to energy savings and carbon emission mitigation.

ACKNOWLEDGEMENTS

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Thermographic Study on Thermal Performance of Rural Houses in Southwest China

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ABSTRACT

The thermal performance assessments of rural houses are often inaccurate by thermal calculation or simulation due to complicated micro climates of rural settlements and the informal processes of self-built structures. Infrared (IR) thermography is an effective and efficient tool to evaluate building and material performance. This study aims to show the possibilities of using IR imaging to better understand the thermal process of rural houses. Several typical rural houses with different kinds of building envelopes in the Southwest of China were selected. A series of thermographs were taken under various circumstances, including different seasons, time periods and weather conditions. Continuous outdoor and indoor air temperature measurements were conducted simultaneously. The results show that the correlationship between envelope surface temperature distributions and air temperature variations of adjoining rooms, as well as the heat gaining and losing processes of different building envelopes.

INTRODUCTION

The study on the thermal environment of rural houses is of great significance. On the one hand the rural structures are often well-acclimated with low energy consumption. On the other hand they may still need improvements to meet higher thermal comfort requirements. However, the thermal performance assessments of rural houses by using regular thermal calculation or simulation tools are often inaccurate. Because the microclimates of rural settlements are often complicated and the informal processes of these self-built structures cannot ensure the fully use of material properties. Furthermore, most rural houses are free running which means natural ventilation is enhanced. Especially in the southwest of China, the locals like having doors and windows open all day long even during the cold winter due to their living habits. Therefore, the simulation results which based on an enclosed-space model and laboratory parameters have low reliability.

Infrared (IR) thermography is an efficient tool to obtain the superficial temperature distribution of the inspected object. It has a broad range of applicability and has been applied to buildings for a couple of decades [1]. IR inspections of building envelopes can be used to detect heat losses, insulation defect, thermal bridges, air leakage and moisture sources, HVAC and electrical installations can also be inspected [2]. It's a very cost effective tool for building diagnostic and retrofit. In addition, this technique can visualize the dynamic heat transfer process through the envelope.

This study aims to show the potential use of IR imaging to better understand the thermal process of rural houses. A four-year field study was undertaken in Wulong County (Chongqing Province) since 2011. A number of research results have been published [4-7]. It is part of Hot Summer and Cold Winter (HSCW) climate zone of China. The outdoor temperature can reach 40°C in summer while it often falls below 0°C in winter, with high humidity all year round. In this study, several typical rural houses with different kinds of building envelopes were selected. A series of thermographs were taken under various circumstances, including different seasons, time periods and weather conditions. Continuous outdoor and indoor air temperature measurements were conducted simultaneously. The results show that the correlationship between envelope surface temperature distributions and air temperature variations of adjoining rooms, as well as the heat gaining and losing processes of different building envelopes.

THE ASSESSED BUILDINGS

The five representative rural houses we chose to take thermographs include two modern ones (built after 1990s) and three traditional ones (built before 1980s), as shown in Figure 1. House (a) and house (b) are three-storey reinforced concrete frame structures, infilled with 390mm x 390mm x190mm cement bricks. The exterior walls are 400mm thick approximately, covered with glaze ceramic tiles. The exterior windows are single-glazed aluminum alloy windows. The ground floors used as garage or store enclosed with metal shutter doors. House (c) was two-storey stone structure built in the 1950s, as the dormitory for slaughterhouse workers. The exterior walls are 500mm-600mm thick with lime plaster layers. The exterior windows and doors are single-glazed framed with wood. House (d) and house (e) are timberwork houses represent the most common vernacular architectural styles in the Southwest China. The exterior windows and doors are same as house (c). The exterior walls are 20-30mm thick wooden boards. House (d) was built in the1930s and house (e) was built in 1961. Some alterations have been made for house (e) and the exterior walls are partly replaced by exposed cement bricks. None of these exterior walls or roofs has thermal insulation layers.

(a) (b) (c) (d) (e)

Figure 1 *Five typical rural houses of different envelopes (a) and (b) Cement brick with ceramic tiles; (c)Stone; (d) Wood; (e) Partly wood and partly cement brick*

METHODS

Four field surveys were conducted on August 26th~27th (2011), April 13th~15th (2012), January 26th~27th (2013) and February 16th~20th (2014), respectively. Both thermographic images and visual images were taken every two hours from 8:00 to 20:00. The indoor and outdoor air temperatures were recorded every 30 minutes. To increase comparability of results, the indoor temperatures have been measured in rooms on the second floor and adjacent to the objective façades. The infrared thermographic camera used in this research is VarioCAM HR Inspect. The information of the instruments is **shown in Figure 2 and Table 1** in details. Thermography is a very cost effective tool, and several methods were applied to prevent inaccuracies.

1. To mitigate the effect of incident solar radiation, we chose the façades facing north or northwest.

2. Parameters that could impact the accuracy of the measurement like material emissivity, ambient temperature and distance from the target are also considered and corrected using software.

3. For building diagnostic, the measurements should performed before sunrise or after sunset to minimize the effect of incident solar radiation. In this case we chose late evening

Table 1. Detailed Information of the Instruments

Physical quantity	Instrument	Range	Accuracy
Surface temperature	VarioCAM HR Inspect	7.5μm~14μm	0.05°C
Air temperature	WSZY-1	-40°C ~100°C	0.1°C

(a) (b)

Figure 2 *The instruments for measurements. (a) is infrared thermographic camera and (b) is hygrothermograph meter*

RESULTS

Diurnal variation of different envelopes

The inspection of exterior surface temperature can illustrate heat gaining and loosing process from dawn to sunset. After sunrise, the external building surfaces start to absorb solar radiation and surface temperature will increase. When environment temperature fall below external surfaces temperature, especially after sunset, heat will dissipated by radiation and the surface temperature will decrease. As the consequence of this heat exchanging process, the indoor air temperature fluctuates along with it. This process can be impacted by material, colour, weather condition and etc.

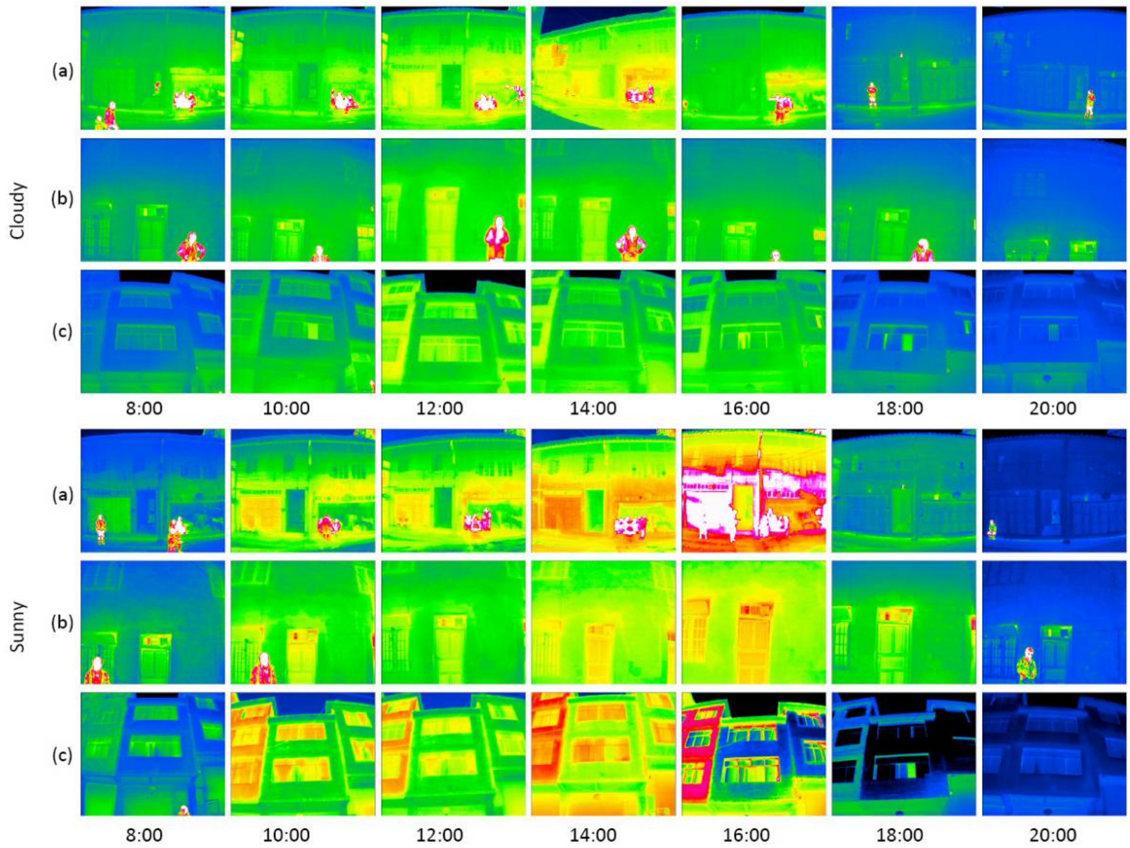


Figure 3 *Thermographs taken on February 16th (cloudy day) and 20th (sunny day), 2014. (a) is wooden board wall; (b) is stone wall with lime plaster; (c) are cement brick walls with glaze ceramic tiles (in the middle) and cement plaster (on the left).*

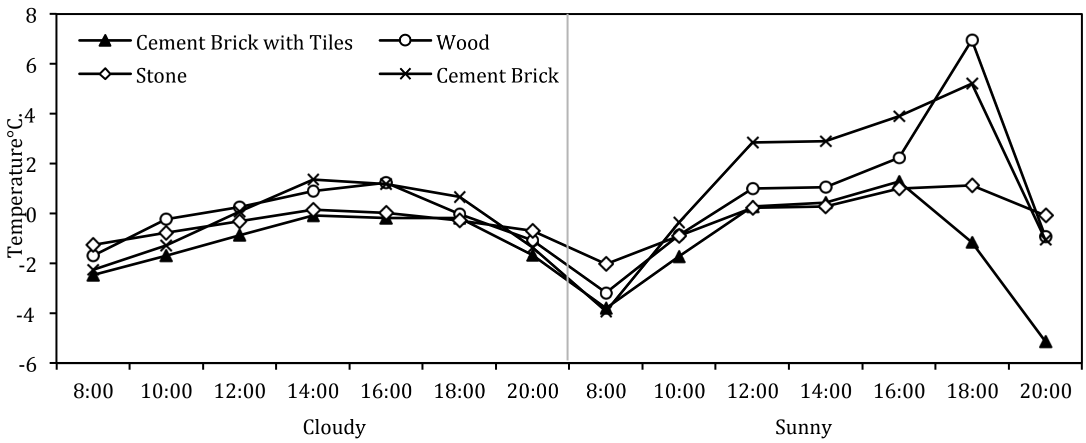


Figure 4 *Average surface temperatures of different building envelopes*

Figure 3 shows a series of thermographs illustrating thermal processes of four different building envelopes in winter affected by the parameters mentioned above. During the period of the measurements, the sunrise time is 7:20 am and sunset time is 6:40 pm. The outdoor air temperatures range from -2.3°C to 2.0°C on cloudy day and -2.1°C to 5.2°C on sunny day. The average outdoor air temperatures are 0.02°C and 1.17°C respectively. The average surface temperatures of different building envelopes were measured through these thermographs, **as shown in Figure 4**. It's important to note that only opaque surfaces were taken into account for calculating the average temperature. That's because it is hard to obtain accurate temperature of glazing unit due to the influence of reflection. Besides, the glaze ceramic tiles can also reflect sky and buildings around it which may lead to errors on the thermographs. **Figure 4** can give us a direct impression that there are great differences in the average exterior surface temperature between different envelopes on sunny day, but little differences on cloudy day. On cloudy day, wooden envelope has the highest average surface temperature of -0.9°C, with the maximum value of 1.24°C. While on sunny day, the temperature of cement brick wall with mortar plastering is the highest, the average value is 1.36°C and the maximum value is 5.21°C. In contrast, the surface temperature of cement brick wall with glaze ceramic tiles is the lowest on both cloudy and sunny days because its light-colored and polished surface has high reflectivity. The average values are -1.02°C and -1.4°C respectively. The surface temperature of wooden and mortar plastering envelopes fluctuate strongly, with the values of 2.93°C and 3.63°C on cloudy day and 10.14°C and 9.14°C on sunny day, respectively. The amplitude of temperature fluctuation of the stone wall is the smallest due to large thermal mass and thermal resistance. On cloudy day, the highest exterior surface temperature is reached around 2:00 pm, while it peaks at 6:00 pm on sunny day except for tiled brick walls. The accumulation of solar radiation is one reason for the difference. Another significant factor is the northwest orientation led the envelope to a western exposure before sunset.

Figure 5 to Figure7 shows the comparison of exterior surface temperature and outdoor/indoor air temperatures of these buildings. It is obvious that the fluctuation of exterior surface temperature is consistent with the outdoor air temperature. No heating equipment has been adopted in the rooms we measured which are adjacent to the envelopes. The interior air temperatures of these rooms are more stable and relatively low. The building with wooden envelope has the lowest temperature but has the highest amplitude of temperature fluctuation valued at 2.3°C. The average temperature is 0.42°C on cloudy day. While on sunny day, the average temperature is even lower (0.28°C). Despite the average temperature of exterior surface is higher than others, the distribution of temperature is uneven. The upper part of the wooden façade adjoining the testing room is shaded by eaves thus has a relatively low temperature. The average interior temperature of building with tiled cement brick walls is the highest (valued at 2.01°C on cloudy day and 2.22°C on sunny day). Even so, the interior air temperatures are far below the thermal comfort range of local residents. According to previous study, the 90% acceptable range in winter is 6.85-13.60°C in operative temperature [5].

From that mentioned above, we can see that the exterior surface temperature is mainly determined by the colour and smoothness of the outermost layer of wall. The light-coloured and smooth surface has a relatively low temperature (as lime plaster and glaze ceramic tile). On the contrary, the temperature of dark and rough surface is higher (as wood and cement plaster). As a consequence, for a higher surface temperature in winter, one should use a dark and rough outer layer for the wall. While in summer, a light and smooth surface is better to avoid overheating. One other thing to note is that the differences between different envelopes is greater on sunny days, but on cloudy days the differences are not distinctive. In consideration of that in this area, most of the days in winter are cloudy, a light-coloured and smooth wall surface is a balanced choice.

Because the influence factors of interior air temperature are more complicated, the relationship between exterior surface temperature and interior air temperature is uncertain. The building with wooden board wall has the lowest indoor temperature while its surface temperature is relatively high. Whereas the glaze ceramic tiles has the lowest surface temperature but the indoor temepratture is higher than the others.

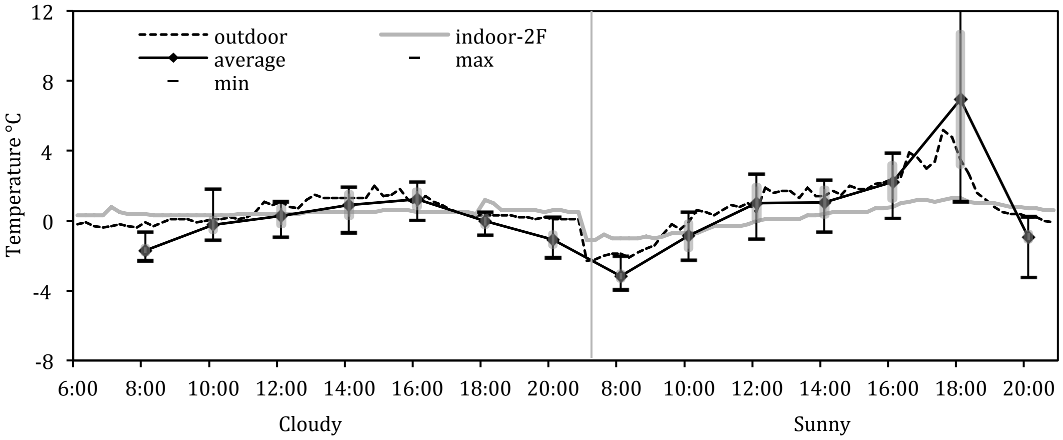


Figure 5 *Surface temperature distribution and indoor/outdoor air temperature of building with wooden walls*

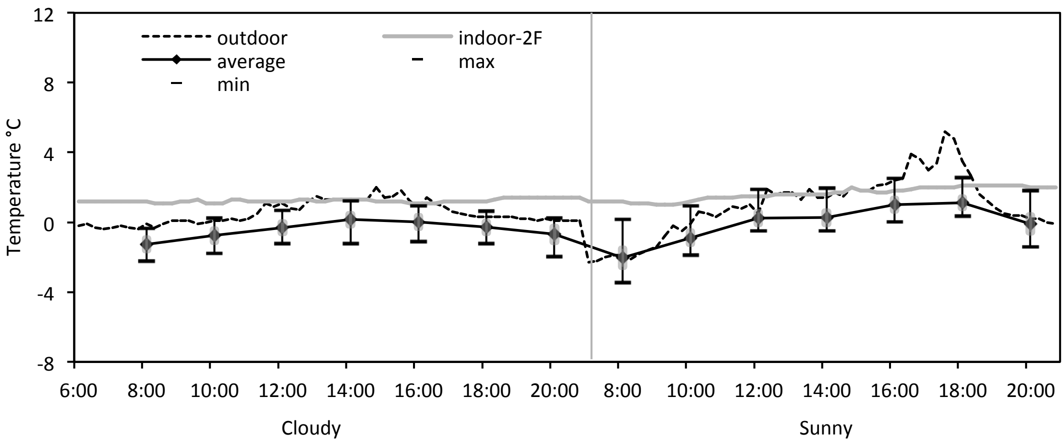


Figure 6 *Surface temperature distribution and indoor/outdoor air temperature of building with stone walls*

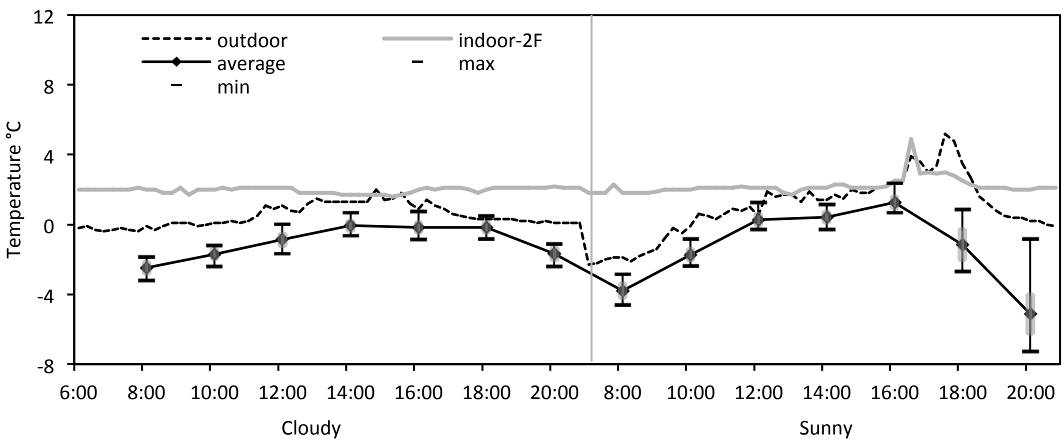


Figure 7 *Surface temperature distribution and indoor/outdoor air temperature of building with tiled cement brick walls*

Seasonal variation of different envelopes

The seasonal variation is distinctive, **as shown in Table 2 and Figure8**. The differences between different envelopes are more significant at higher temperatures. In February, the average exterior surface temperature of wooden façade is 0.66°C higher than that of stone wall. In April, the average exterior surface temperature of wooden façade is still the highest, valued at 13.96°C. While the stone façade and the brick façade have the similar temperature valued at 12.99°C and 12.97°C respectively. The temperature gradient is approximately 1°C. In August, the temperature gradient reaches 5.13°C. Wood façade still gets the highest temperature of 27.45°C. And the temperature spans are wider in summer than the other two seasons.

Table 2. Thermographic Records of Different Seasons (10:00 am)

° C	Avg	Min	Max	Span	SDev
WINTER (19th February, 2014)					
Wood	-0.23	-1.13	1.81	2.94	0.34
Stone	-0.89	-1.87	0.94	2.81	0.35
Tiled Brick	-0.87	-2.24	0.49	2.73	0.74
SPRING(15th April, 2013)					
Wood	13.96	12.75	14.51	1.75	0.31
Stone	12.99	12.54	13.75	1.20	0.18
Tiled Brick	12.97	12.56	13.62	1.07	0.15
SUMMER(27th August, 2011)					
Wood	27.45	24.17	30.94	6.77	1.86
Stone	25.34	23.45	27.33	3.88	0.83
Tiled Brick	22.32	18.81	25.77	6.95	2.44

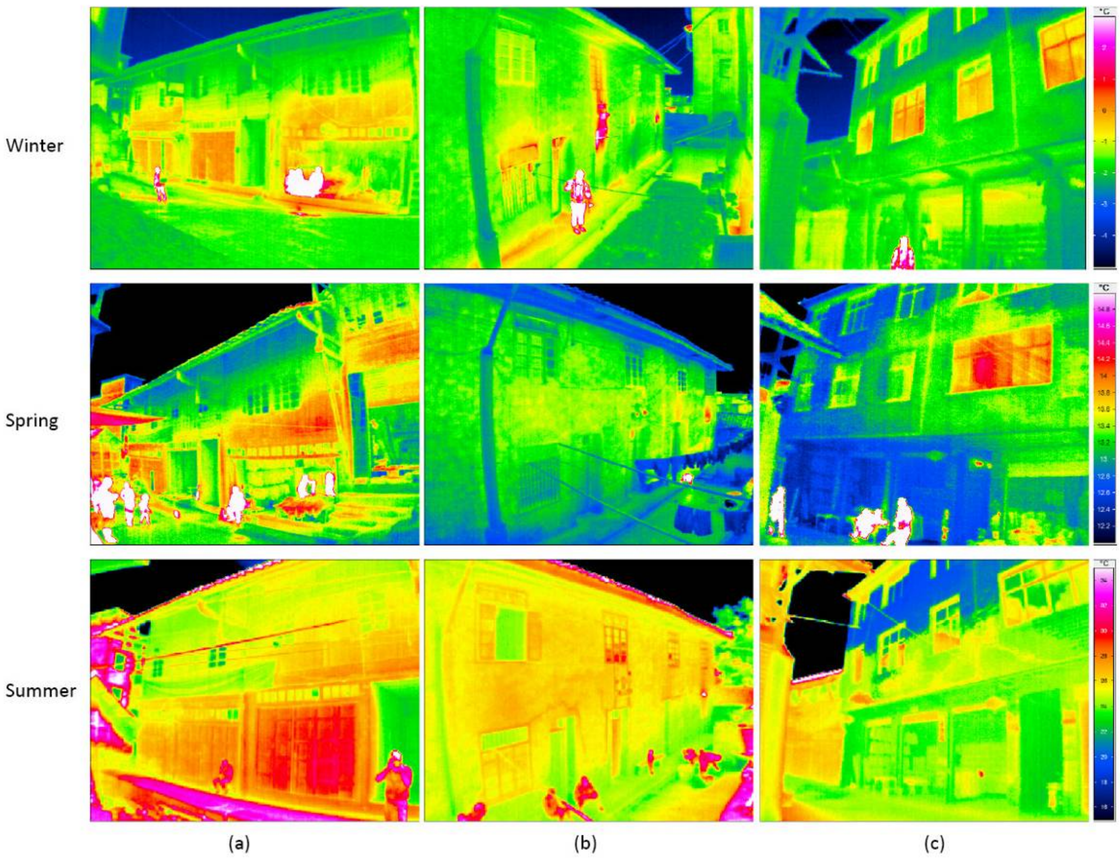
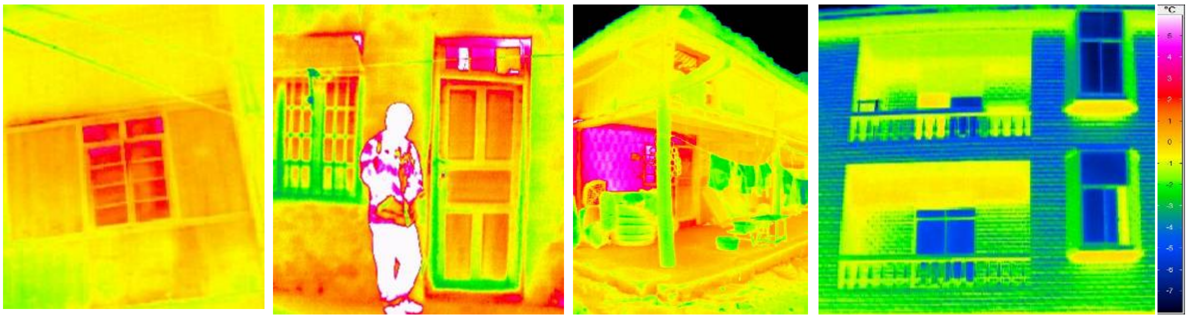


Figure 8 *Seasonal differences. (a) is the building with wooden walls; (b) is the building with stone walls; (c) is the building with tiled cement brick walls*

Building diagnostics

The most common use of IR thermography is for building diagnostics. It can be used to identify air leakage through openings, heat losing areas and moisture problems. To minimize the effect of incident solar radiation, the measurements for detecting building defects were performed at late evening (at 8:00 pm, on February 20th, 2014), **as shown in Figure 9**. Thermographs (a) and (b) show windows or a door frame viewed from exterior. The “red lines” along the top of the openings show the locations for hot air exfiltration. Thermograph (b) also indicates the possible water damages at the foot of the stone wall. The surface temperature is higher in this area, since the heat is conducted through wet mass more rapidly from interior. The red part of the façade in thermograph (c) is exposed cement brick wall with no insulation. (d) is the thermograph of a reinforced concrete building. The brighter parts under the eave and balconies are exposed concrete slab. There’s no obvious air leakage around the openings, which may explain the fact that the indoor air temperature is higher than timberwork and stone houses even if the heat gains through the building envelopes are less. These resluts suggest that to improve building performance in this area, some measures should be adopted. Fill up the wall cracks and gaps around openings. The building foundation should be dampproof and waterproof. Thermal insulation mortar or polystyrene board can be used for building exterior walls.



(a) (b) (c) (d)

Figure 9 *Detailed thermographs of building defects (a) shows the second floor window of a timberwork house; (b) shows the window and door of a stone house; (c) shows the exposed cement brick wall of a timberwork house; (d) shows windows and balconies of a reinforced concrete house*

CONCLUSIONS

In this study, the infrared thermographic measurements of rural houses were conducted in the Southwest of China from 2011 to 2014. The results show that there are significant daily variation and seasonal variation differences between different building envelopes. The common defects have been revealed with the help of infrared thermography. Following conclusions can be made

1. The exterior surface temperature is mainly determined by the colour and smoothness of the outermost layer of the wall. Light-coloured and smooth surface has a relatively low temperature, while the temperature of dark and rough surface is higher. The differences between different envelopes is greater on sunny days, but on cloudy days the differences are not distinctive. In consideration of that most of the days in winter are cloudy, a light-coloured and smooth wall surface is a balanced choice for this area.

2. The fluctuation of exterior surface temperature is consistent with the outdoor air temperature. On the contrary, the correlationship between exterior surface temperature and indoor air temperature is not obvious. The indoor temperature is also related to the envelope structure, thickness of wall, type of openings and other factors.

3. The seasonal variation is distinctive. And the differences of surface temperature distribution

between different envelopes are more significant at higher temperatures. The temperature spans more widely in summer than the other seasons.

4. To improve building performance in this area, some measures should be adopted. Fill up the wall cracks and gaps around openings. The building foundation should be dampproof and waterproof. Thermal insulation mortar or polystyrene board can be used for building exterior walls.

ACKNOWLEDGMENTS

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Regeneration and Recovery

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REGENERATION AND RECOVERY

One of the most important lessons that we have learnt as an architectural practice with a concern for sustainability is that a project, in an Indian context, never proposes itself with a well defined agenda. With each project, based on the program, the environmental context, the social interconnection and the economic limitations, as architects, we have had to define an approach to sustainability that is unique to that project. Our approaches have ranged from questioning the need to build - to building with materials and construction systems so that recovery or regeneration is possible. In this process, we have arrived at some specific design processes and methods of engagement with an environment. This paper aims at identifying these tools and methods with reference to their unique relationship to the project. It will first present a framework of issues and concerns that has emerged through our engagement with various contexts and then go on to detail out the design processes of four examples with specific concerns of regeneration and recovery and go on to identify its impact on energy demands. More importantly, it will also go on to identify the other social and ecological effects of these processes.

INTRODUCTION

Architecture in Indian urban context has not seen the pace of change that it has seen in the last ten years and that is likely to continue in the coming 20 years. This means a large number of buildings are going to be domilished and rebuilt. In our practice of 15 years, we have rarely had a land with no existing buildings on it, some of them were not older than 20 years. Construction and demolition are closer to each other than we want to believe and in this perspective, one of the most important challenges of sustainability is on one hand the constant need for resources to make new buildings and on the other hand the constant waste the demolition produces. In his book *Architecture Depends*, Jeremy Till quotes from a lecture by Prof. Peter Guthrie that 'all architecture is but waste in transit!' (Till, 2009. Pp. 67). His intention is to question the notions of 'value' of architecture. For our practice, this thought has provoked a particular response to all our projects.

INTENT AND OBJECTIVES OF APPLIED RESEARCH/BUILT WORK(S)

Highlighted in this paper are processes followed in four projects that are representative of the approach. These projects are not explained in a chronological order but in the order of its invasiveness on to an existing built environment and impact on resources. The levels of invasiveness identified below form our framework with which we approach each of our projects:

Level 1: Why Build? What are the values that the new intervention is adding? Are there any non-negotiable values in the existing built environment (social, cultural, environmental)?

Level 2: Why not Reuse? Is there a possibility of adapting existing buildings to new programs, with or without alterations?

Level 3: Recover and Regenerate. Can the existing material on site be recovered, recycled or regenerated for new use?

Level 4: Design for Recovery. Design for spatial polyvalence and as components that can be easily recovered for a different use. .

PROJECT 1 - WHY BUILD?

A rural school with a capacity of 3000 students in South Gujarat needed facilities such as an Auditorium for large gatherings, an office space, a library and a couple of seminar spaces with audio – visual projection facilities. The client approached us with a clear programmatic requirement of 1250 sq.m. This was an addition to an already existing campus with 6756 sq.m. of built up area. Our initial response was to go ahead and design buildings as per the requirement and present it to the clients (a group of trustees and teachers) for their feedback (figure 1). This generated a debate about the 'value' that introduction of these facilities would bring to the campus. It was found that the ground cover of the new addition in best case scenario would reduce the playground available for the children. At the same time a substantial school fund would be required, some of it otherwise could be used for the water and sanitation upgradation.

This led us to a detailed analysis of the existing buildings and spaces with reference to the new requirements (figure 3). We found that the existing buildings had a reasonable amount of redundant spaces as they were not suitable to changing needs of the school over the period of time. A proposal for reorganization and consolidation freed up spaces and could be adapted to needs of the new program (figure 2).

- A covered gathering space instead of an auditorium could be created by covering up the open space between the two wings of a building and an elevated platform was carved in the third wing to act as a stage.
- Office and Seminar space requirements were accommodated in the existing buildings.
- An elevator and bridges were introduced for better connectivity and accessibility.
- One building of 110 sq.m. was added at the edge of the playground leaving the rest of the area undisturbed.

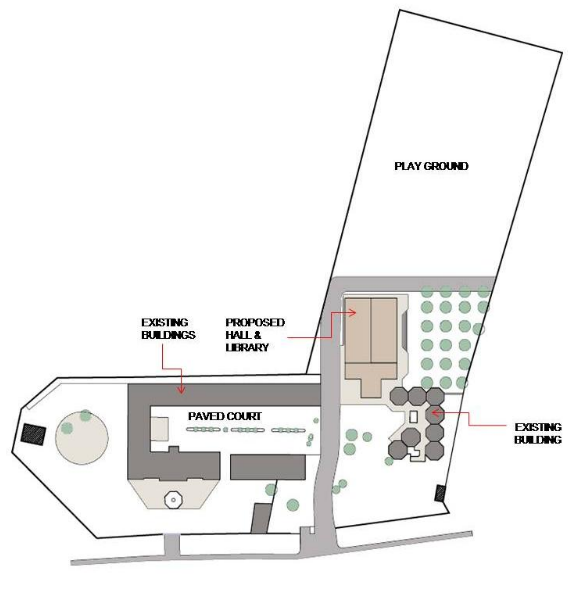

Figure 1 *Initial design proposal.*

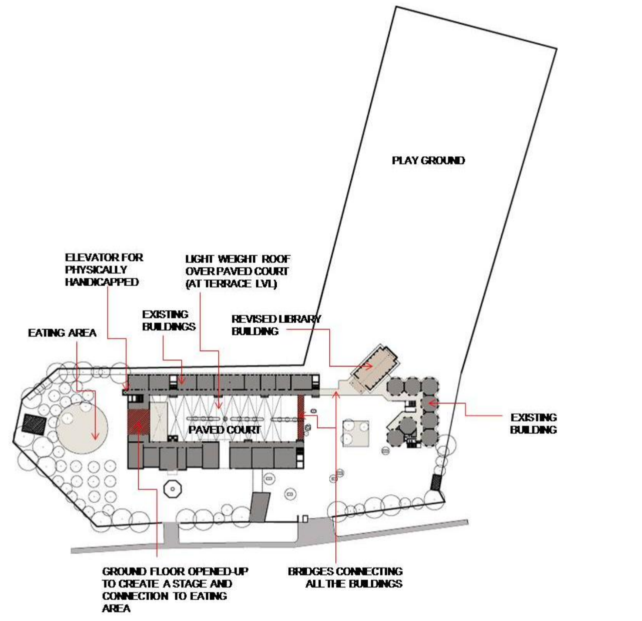

Figure 2 *Revised design proposal.*

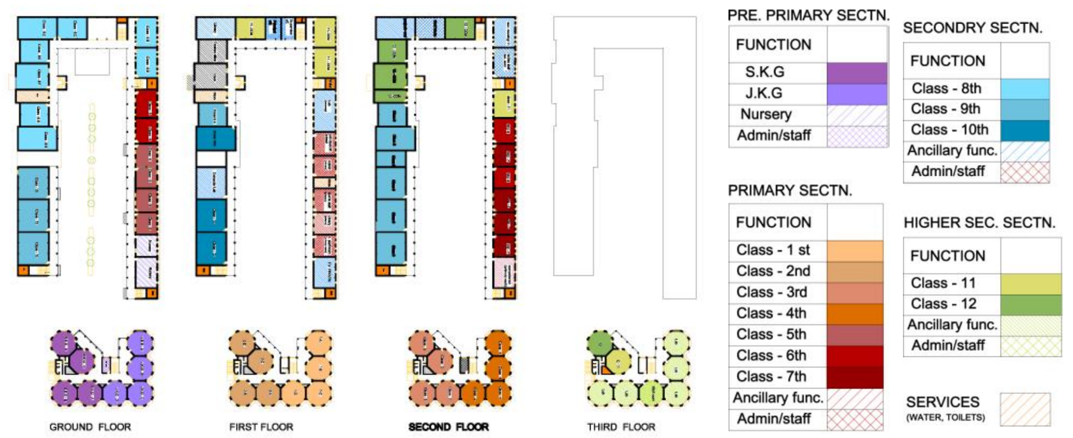

Figure 3 *Space use study of the existing school buildings.*

PROJECT 2 – WHY NOT REUSE?

The project brief was to demolish an existing 'marriage hall' of 1275 sq.m. and construct a new office building of 1900 sq.m. Looking at the quality of existing building it was possible to convert the same into an office building with certain infrastructural additions and retrofitting. However, this would not have fulfilled the area criteria of the new program. Therefore

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we carried out an extensive Cost Benefit Analysis of various possible scenarios to arrive at an informed decision (Table 1).

Table 1: Cost Benefit Analysis

	Scenario 1:	Scenario 2:	Scenario 3:	Scenario 4:
Strategic Approach	**Retain and renovate existing G+2 Bldg.**	**Strengthen the existing bldg. and add one floor above to get G+3 bldg.**	**Insert lightweight floors within the existing bldg. ht to get G+3 bldg.**	**Demolish existing bldg and construct a new G+4 bldg.**
Total Built up Area	1275 sq.m.	1590 sq.m.	1590 sq.m.	1900 sq.m.
Cost of Construction	Rs. 94 lac	Rs. 145 lacs	Rs. 150 lacs	Rs. 185 lacs
Cost per sq.m.	Rs. 7372	Rs. 9120	Rs. 9435	Rs. 9735
Time Factor	8–10 months	15-18 months	12–15 months	15-18 months

Scenario 2 and 3 were not considered further as there was very little difference in cost per sq. m. and time factor in comparison to Scenario 4. Furthermore, the new building proposed in Scenario 4 would have a significantly more life span. Scenario 1 and 4 were considered further for their other qualitative aspects (Table. 2).

Table 2: Other considerations

Strategic Approach	Scenario 1: Retain and renovate existing G+2 Bldg.	Scenario 4: Demolish existing bldg and construct a new G+4 bldg.
Advantages	• Utilization of existing resource. • May not be necessary to provide parking facility as per current by-laws. • Low time of construction. • Large and clear hall space without any columns.	• New building designed to requirements. • New building will have permissible FSI of 1.5 instead of existing FSI of 1.3 thus can get additional area. • All facades and climatic features could be integral part of the building.
Disadvantages	• No provision for extension in existing structural system. • Structural alterations like flattening of existing stage, filling of void on first floor, ramp to basement, reconstruction of entire front bay are mandatory. • Infrastructure facilities like circulation core of lifts and stair, electrical supply, water tanks and plumbing are to be constructed anew. • Existing floor to floor ht. of 4.6m may mean higher running cost of the building.	• Parking provisions to be made as per current by-laws (30% of max permissible FSI), which may require providing second basement. • High Construction Cost • More time required.

Figure 4 *Existing building and views of the proposed retrofitting*

This became the basis for the client to arrive at an informed decision of retaining the existing structure and adapting and retrofitting it to the new program (Scenario 1). The design process considered and mitigated the major disadvantage of higher floor height resulting into higher energy costs by integrating a climate control envelop on the west and south façade (figure 4).

PROJECT 3 – RECOVER AND REGENERATE

Commissioned to redesign an institutional campus, our thorough study of existing buildings suggested that they be demolished and rebuilt. In this case, instead of following a mass demolition process, we decided to dismantle the buildings brick by brick and bring the recovered material into use (figure 5). Table 3 quantifies the recovered materials and the potential of regeneration.

Figure 5 *Images of the various material recovery processes.*

Table 3: Material Recovery table

Material Recovered	Quantity	Area of Use
Bricks	50,000 bricks (60% of 630 sq.m. structure)	The brick strength was found to be equivalent to the new bricks (5.0 N/sq.mm). Normally these bricks are channelised in the informal market of low cost construction. The project team decided that it would be socially irresponsible to take away this affordable resource from the needy. Hence, these bricks are not going to be used for this project.
Natural Stone Flooring	400 sq.m.	To be reused in the new building
Steel (from R.C.C elements)	6,650 kg.	Most of the steel and wood was degenerated. Some material that was found in good condition was recovered as elements and channelized in the informal market for the same reason as the bricks.
Wooden Doors/ Windows	10 nos.	
Steel Grills	1,425 kg.	
Concrete debris & Nominal brick debris	1,200 MT	The debris will be sorted in large chunks and sandy residue. Large chunks of concrete debris, after suitable screening and sizing will be used as aggregate replacement in fresh concrete upto 30% of the total aggregates. The sandy residue will be used to manufacture bricks in the standard size of 230mm X 110mm X 75mm. The mix will consist of: Demolition waste: 85 - 94%, Binding material (lime and cement): 6 - 8%, Fly ash: remaining amount. The mix will be designed to give a brick strength of 7.5 N/sq.mm with water absorption below 15%.

The process of recovery had its lessons for new construction.

- Buildings more than 30 years old generally give a better recovery. Other factors that help are; correct mortar mix (mortar strength should be less than the brick), uniform brick sizes and quality of bricks (older the buildings, better the quality of bricks).
- The natural materials are far more conducive to recovery compared to manufactured tiles. One of the important learning was that the bedding must not contain any binder ('morthuthu', glue, epoxy etc.) other than the requisite cement.
- Structural Steel is extremely easy to recover and reuse. However, the reinforcement steel can be recovered and down cycled as non structural steel.

PROJECT 4 – DESIGN FOR RECOVERY

Challenged with a project for a weekend house at a site with steep slopes, very little flat land and loose sandy soil of ravine, we decided to intrude as less as possible on the terrain and in a manner that the building, when needed, can be fully dismantled and material/ elements recovered (figure 6). As a result the program was divided in smaller components with each component designed to touch the ground lightly.

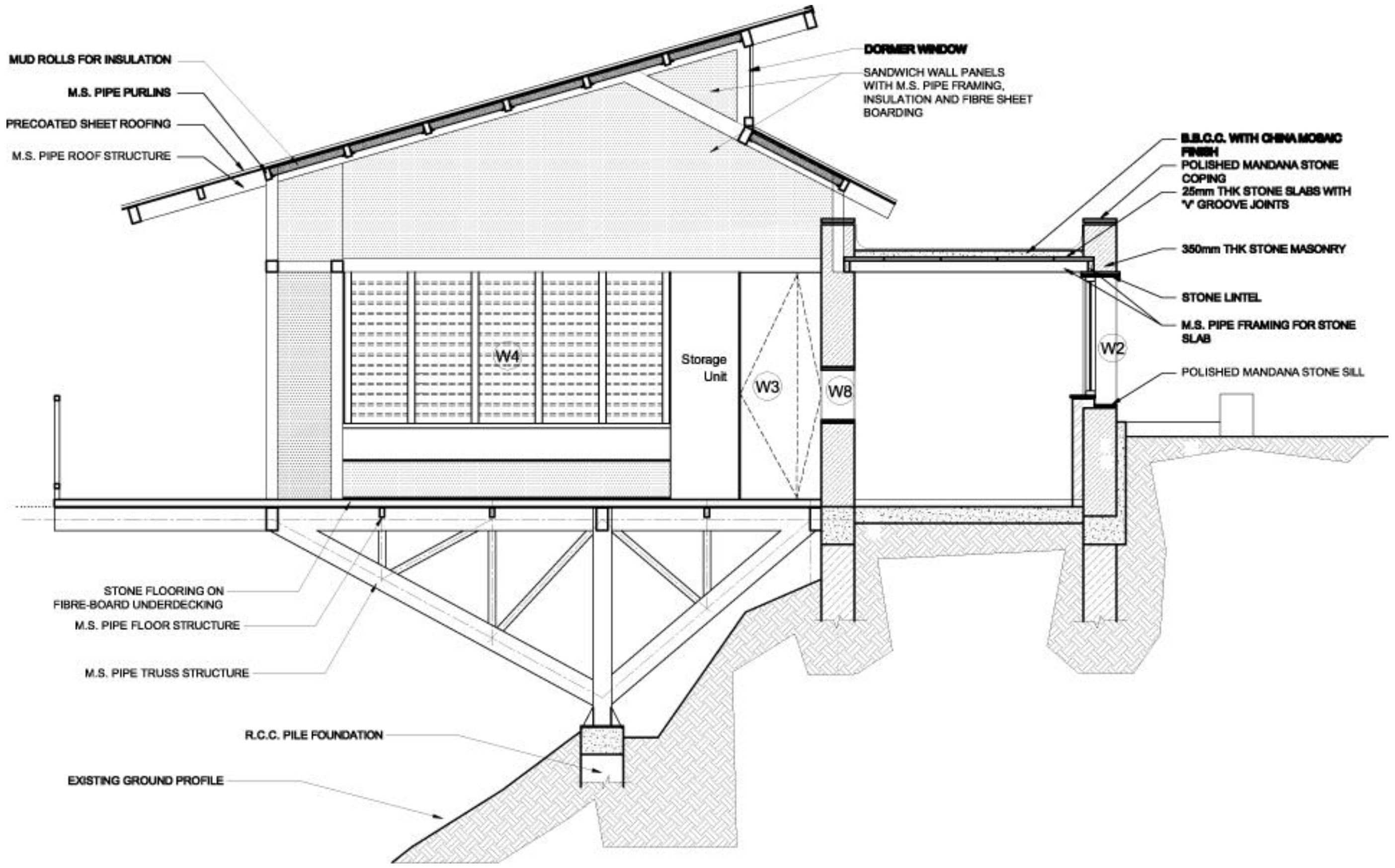

Figure 6 *Section through the proposed building unit.*

Figure 7 *Images of the buildings under construction.*

INFERENCES AND CONCLUSION

	Energy Impacts	Social Impacts
Project 1 (Why Build?)	Built up area reduced due to the space efficiency study: 1140 sq.m (more than 90% reduction in original programmatic require). Elements added for better functionality of the existing building: Elevator, central court cover, bridges.	Playground remains undisturbed. The negative spaces are converted to active spaces. The available funding to be diverted for better amenities and site management.
Project 2 (Why not Reuse?)	Retrofitting will consume only 30% of the energy required to demolish and construct a new building. The façade screen treatment on South and West sides reduces the operational energy requirement by 25%, thus mitigating the negative aspect of higher floor to floor height	--
Project 3 (Recover and Regenerate)	Approximately 7.5 lac MJ of energy saved through material recovery and through using waste for generating new material (in comparision with procuring available bricks).	Sand and top soil used for making conventional bricks is avoided. Availability of recovered materials provides affordable resources for low cost construction in informal sector housing.
Project 4 (Design for Recovery)	Though the embodied energy of the structure is higher than the conventional concrete structure, its design for material/ components retrievability at the end of life cycle makes it sustainable.	--

This paper has discussed four resource centric approaches to sustainability. It is estimated that India generates close to 530 million tones of construction and demolition waste per year. While a regulatory mechanism to check this loss of precious resource is in a very nascent stage, we as architects have to consider it our responsibility towards a judicious employment of construction materials. This can be approached at various stages of the project:

DESIGN STAGE:

1. Evaluation of the contextual relevance, relationships and possibilities of reuse.
2. Optimisation of existing structures, if any.
3. Rationalisation of design to maximize the efficiency of structure and other building elements.
4. Selection of materials with reference to local availability, technological feasibility and possibilities of recycle/ reuse at the end of the life-cycle.
5. 'Design' and management of the demolition as a process of dismantelling to recover building materials.

CONSTRUCTION STAGE:

1. Though currently it is difficult to include waste management as a contractual obligation, a codification of materials selection, their procurement policies and procedures ensures resource consciousness amongst all the stake holders of the project.
2. Creating awareness of construction materials as energy intensive resource also helps in ensuring waste minimisatin right from the client to the construction workers.

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Aggregating building energy demand simulation to support urban energy design

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ABSTRACT

Designing energy efficient cities and in particular designing buildings as well-thought components of the urban fabric and active components of the urban energy system requires reliable information on the current demand in energy within buildings, its distribution in time and space and the possibility to impact on this demand.

In this article we present a methodology developed to produce this information by aggregating the simulation results of a very large number of buildings. The methodology relies on the use of an existing simulation tool (bSol) and of selected default parameter values corresponding to pre-defined building typologies as well as data from existing weather and GIS databases for calibrating the tool. The core challenge being the adequate choice of default parameters related to the building's environment (weather conditions and surroundings), its fabric (mass and envelope), its equipment and its occupants' behaviour, we pay special attention to producing a sensitivity analysis of the tool's results in relation to these parameters. This leads us to define a database structure for required default values and to start populating the database with robust values.

We apply the methodology to recognise typical urban typologies relevant to energy planning and the parameters defining them, such as building typologies, mixity of use, urban density and morphology, existing energy infrastructure, potential for renewable energy production. For each urban typology we attempt to propose typical solutions at different levels of spatial resolution, ranging from decentralised solutions to more centralised solutions at neighbourhood, district or city level.

While the methodology presented was developed within a Swiss project it can just as well as be applied to the challenge of planning and implementing energy efficiency in rapidly growing cities of developing countries, in particular to the regeneration of existing and planning of new city districts.

INTRODUCTION

It is widely accepted that an integrated multi-energy approach covering energy demand, supply, distribution and storage applied to a cluster of buildings (neighbourhood, district or whole city) is required for the optimal planning and design of urban energy systems. One of the main challenges in this field is being able to simulate the energy demand (in particular heating and cooling requirements) of large numbers of buildings at an acceptable level of accuracy.

While building simulation tools are currently capable of simulating single buildings within a reasonable level of accuracy provided a great amount of information is made available to calibrate the tools used, simulating a large number of buildings and their aggregated demand profiles with very little input data remains a core challenge. With increasing computational power the issue is no longer computational run time but rather a reliable estimation of the discrepancy between simulated and real demand profiles (and the reduction of this discrepancy). This information is vital if we wish to rely upon building simulation for the detailed design and operation of urban energy supply and distribution infrastructure. We present in this article a methodology to address this issue consisting in proposing well defined building typologies with a minimum amount of significant input parameters that can be used to calibrate an existing building simulation tool.

STATE-OF-THE-ART

Previous efforts to model a large number of buildings have been made in particular to support cities in their energy planning. Projects worth noting, for example in Switzerland, are EnerGIS [Girardin et al., 2010], MEU [Rager et al., 2013] and Zernez [Orehounig et al., 2013]. In the case of EnerGIS the energy demand from the building stock of the city of Geneva was represented by a set of 80 building typologies each corresponding to a thermal signature. The two latter projects use the CitySim [Robinson et al., 2009] simulation tool to produce hourly energy consumption profiles of buildings in either the neighbourhoods of the cities of Lausanne, Martigny, La Chaux-de-Fonds and Neuchâtel in the case of the MEU project or the alpine village of Zernez.

At the European level the introduction of compulsory European Performance Certificates has generated a large amount of data on the annual energy demand of buildings as well as a variety of national calculation methods to estimate these. The TABULA project (and its follow-up project, EPISCOPE [Episcope, 2014]) proposes national building typologies typically based on the year of construction and on the size (with categories “single-family”, “terraced”, “multi-family houses” and “apartment blocks”) of the buildings, mostly limited to residential buildings, for each of the 13 countries involved. While the main objective of the project is to inform users regarding the potential for energy demand reduction in “normal” and “ambitious” scenarios of refurbishment and the associated costs it represents an extremely valuable dataset of default values that can be used for parametrizing dynamical simulation tools.

METHODOLOGY

The methodology presented in this article was produced in the on-going Smart Heat project [Smart Heat, 2014] whose objective it is to propose to the energy utilities of Verbier and Sierre a preliminary solution (system design and operation strategy) for meeting the thermal loads of the buildings of each town in line with their urban energy plan. OSMOSE, a tool for the design and analysis of integrated energy systems developed by the Ecole Polytechnique Fédérale de Lausanne (EPFL) [Fazlollahi et al., 2014] is used within the project to define the best possible energy conversion system for the use case, combining centralized and decentralized solutions, by using its thermo-economic optimization functionalities. In order to produce this output OSMOSE requires the knowledge of the dynamical behavior of energy demand of all buildings. For this we use the bSol software [Bonvin et al., 2007] to simulate single buildings or building zones. bSol produces a profile of hourly heat requirements to compensate for heat losses over the previous time step, but does not model the buildings’ energy production and distribution (HVAC) system. It calculates losses based on the thermal balance of heat transferred through the building’s surfaces, heat transferred via air exchanges and internal heat gains due to solar radiation, occupant presence and use of appliances. This calculation requires the user to input parameters related to the building’s fabric (e.g. U-values of the building’s envelope elements, thermal capacity, glazing ratio and g-value of windows), its use (e.g. occupant presence profiles, installed capacity of electrical appliances, temperature set-points, air exchange rates, use of blinds) and meteorological data (extracted from the METEONORM database [Meteonorm, 2014] for the site in question) such as outdoor temperature and solar radiation (taking into account the topography of the site).

bSol has the avantage of existing in a stripped-down server-based version capable of treating, within seconds, batches of simulation runs containing values for the input parameters and returning simulation outputs for each building. This version was used to simulate the energy demand of large numbers of buildings in order to determine the energy demand of neighbourhoods, districts or the whole town. This approach transfers the problem of large-scale energy demand simulation to that of 1) defining the right inputs parameters for a large set of buildings and 2) aggregating the results of single building simulation to produce realistic energy demand profiles at various levels of spatial resolution.

The problem of producing input parameters for large sets of buildings is best solved by defining building typologies that can be easily related to statistical information available on a building by building basis. The Swiss federal office of statistics [Federal land registry office, 2014] provides geo-referenced information for each building in the country. The Centre de Recherches Energétiques Municipales (CREM) combines this information with other sources of information (e.g. from the trade register) to provide their own geo-referenced database named PlanETer [Cherix, 2011], conceived to support municplities in the development of their energy masterplan and that is gaining in widespread use amongst municipalities in western Switzerland.

We use the following information for each building: location, year of construction, year of refurbishment, building use, building footprint (typically provided as perimeter and surface) and number of stories. On the basis of this information we define building typologies based on the *year of construction* and the *building use*. Categories for the year of construction are defined as:

A - "Previous to 1980",
B - "From 1981 to 1990",
C - "From 1991 to 2000"
D - "From 2001 to 2010"
E - "After 2010"

Categories for building use[1] correspond to:

1 – "Residential"
2 – "Residential - seasonal[2]
3 – "Restaurants"
4 – "Restaurants - seasonal"
5 – "Hotels"
6 – "Hotels - seasonal"
7 – "Commercial"
8 – "Schools"
9 – "Administration"
10 – "Industrial"
11 – "Sports halls"

This allows us to represent the great majority of buildings to be simulated with 55 building typologies. To each of these typologies we associate the full set of input data required to run a bSol simulation (see figure 1). While some inputs are currently fixed for all typologies the values of the following input parameters depend on the typology:

- for the building fabric: U-values of the roof, facade, floor, windows and window frames, glazing ratio of each facade, g-value of windows, total thermal capacity;
- for the building use: temperature set-point, installed maximum heating capacity, occupancy profile and installed electrical appliance capacity (for the calculation of internal heat gains).

The choice of numerical values for these parameters has been made to coincide with national building regulations (e.g. SIA 380/1, SIA 2024) when possible and based on the authors' expert knowledge when not. Each building is simulated as a rectangular polyhedron facing southwards with no obstruction other than the topography of the site (i.e. not considering neighbouring buildings). The choice of intervals for years of construction was based on the authors' expert knowledge; its pertinence is assessed in the sensitivity analysis.

[1] Buildings not covered by these categories (e.g. churches, farms) are currently considered individually but can also be added to the list of typologies.
[2] The distinction between "seasonal" and "non-seasonal" categories is intended to account for the significant seasonal dependence of building use in touristic resorts, such as Verbier.

Year of construction	Building Use		Thermal coefficients							Glazing ratios			
			U Roof	U Facade	U Floor	U Window pane	U Window Frame	g	Thermal capacity MJ/K.m^2	North	South	Est	West
<=1980	Residential	A1	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Residential - seasonal	A2	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Restaurants	A3	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Restaurants - seasonal	A4	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Hotels	A5	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Hotels - seasonal	A6	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Commercial	A7	1.00	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Schools	A8	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Administration	A9	0.80	1.10	1.50	3.00	2.00	0.80	0.50	15%	30%	20%	20%
	Industrial	A10	0.80	1.10	1.50	3.00	2.00	0.80	0.25	15%	30%	20%	20%
	Sports halls	A11	0.80	1.10	1.50	3.00	2.00	0.80	0.25	15%	30%	20%	20%

Figure 1 Sample of the inputs associated to 11 of the 55 building typologies and required to run a bSol simulation of a building.

DISCUSSION OF RESULTS

It was not possible to acquire energy demand profiles of the buildngs being modelled within the Smart Heat project. The application of statistical analysis on measured data to validate the methodology presented here will be done in further research. In the meantime we have focused our efforts on carrying out a sensitivity analysis of our model to 1) confirm our choice of typologies based on *year of construction* and *building use* and in particular our choice of categories for these parameters, 2) understand which input parameters associated to each typology have a significant impact on the simulation results. This latter analysis is important as it will also highlight which data needs to be collected in the future to validate the model and to improve the values of input parameters.

In order to confirm the choice and number of typologies we produced an analysis of variance (ANOVA) to assess whether the year of construction and the building use are indeed decisive factors allowing one to distinguish between simulations of annual energy demand. Each category of *year of construction* is associated to a unique total U-value of the building envelope (A – 1.36W/m^2/K, B – 0.89W/m^2/K, C – 0.65W/m^2/K, D – 0.46W/m^2/K, E – 0.32W/m^2/K). Each category of *building use* is associated to a unique occupancy profile, value of installed capacity (of electrical appliances) and value of air exchange rate.

The ANOVA was applied to the results of 165 simulation runs, i.e. 3 runs per typology corresponding to three states of temperature set-point: 19.5, 20 and 20.5°C. This corresponds to the typical precision of a building's thermostat, independent of its year of construction and building use, and allows us to introduce a common variability to the simulations of each typology. A two-way ANOVA was applied on the variability of energy demand for each couple (year of construction, building use). This produced an F-test value of 11.29 that has a probability smaller than 2*10^{-16} of following a distribution of Fischer-Snedecor with ν_1=40 and ν_2=110 degrees of freedom and confirms our assumption that the couple of parameters (*year of construction*, *building use*) is relevant in classifying the simulated energy demand of buildings and a reasonable choice of building typologies.

In order to visualize the impact of the *year of construction* and the *building use* on our simulation outputs of interest (annual energy demand, peak and average power demand) we also analysed the probability distribution of annual energy demand as a function of these two parameters separately. Figure 2 shows the boxplots of these distributions for categories A to E in the case of a residential building. The parameters shown are the median and average power demand (over one hour), the number of hours of heating over a year and the 95th percentile of the distribution representing a reasonable estimate for the "maximum power demand" that should be used to size the heat production system. The average power demand of each category lies beyond the inter-quartile range of the previous category confirming our assumption that these distributions are distinctly different from each other that this choice of categories was appropriate.

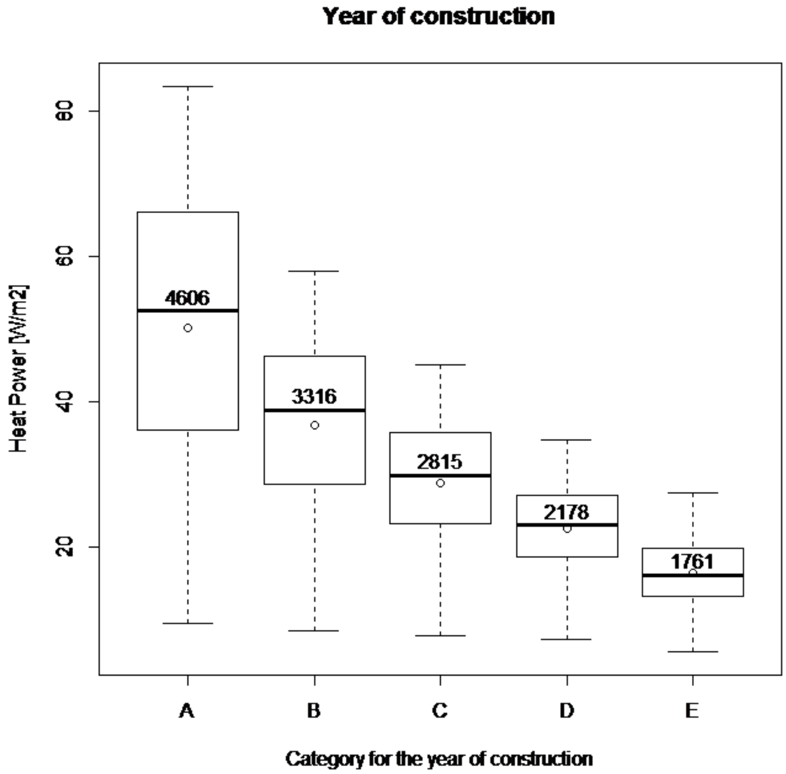

Figure 2 Distribution of power demand for categories A to E including the total number of heating hours, average power (circle) and 95th percentile (upper tail of the boxplots).

We then run, for each category A to E, simulations corresponding to the 11 different building uses. The annual energy demand[3] value of each building use is represented by a symbol in the graph of figure 3. The average (mean) and standard deviation (sd) of the distribution of the 11 values per category of year of construction are given in the table on the right. The first observation is that the order of results stays the same for each category A to E. This proves that there is a systematic dependency of annual energy demand related to building use, in other words that the heat gains and losses associated to a specific building use are not affected by the building fabric in such a way that results could be interverted. They are therefore distinguishable from each other; the question is whether the spread due to other input parameters (discussed below in the design of experiments displayed in table 1) overwhelms the spread related to building use. Aside from outdoor obstruction building use proves to have the highest impact on simulation results. Also this impact (the ratio between “sd” and “mean”) increases for newer categories of buildings for which distinguishing between building use becomes essential. We conclude that distinguishing between building use is necessary for most years of construction and should not be limited to newer buildings but be applied to all categories A to E. In addition to determining the way a building is used, building use categories also determine the building fabric elements typically associated to a building use, confirming even more so the need to consider all 11 categories for each year of construction.

[3] Values for mean power show similar results. Values for maximum power were not representative due to the fact that the 95th quantile corresponded, for a large number of building use categories, to the nominal power entered as an input into bSol.

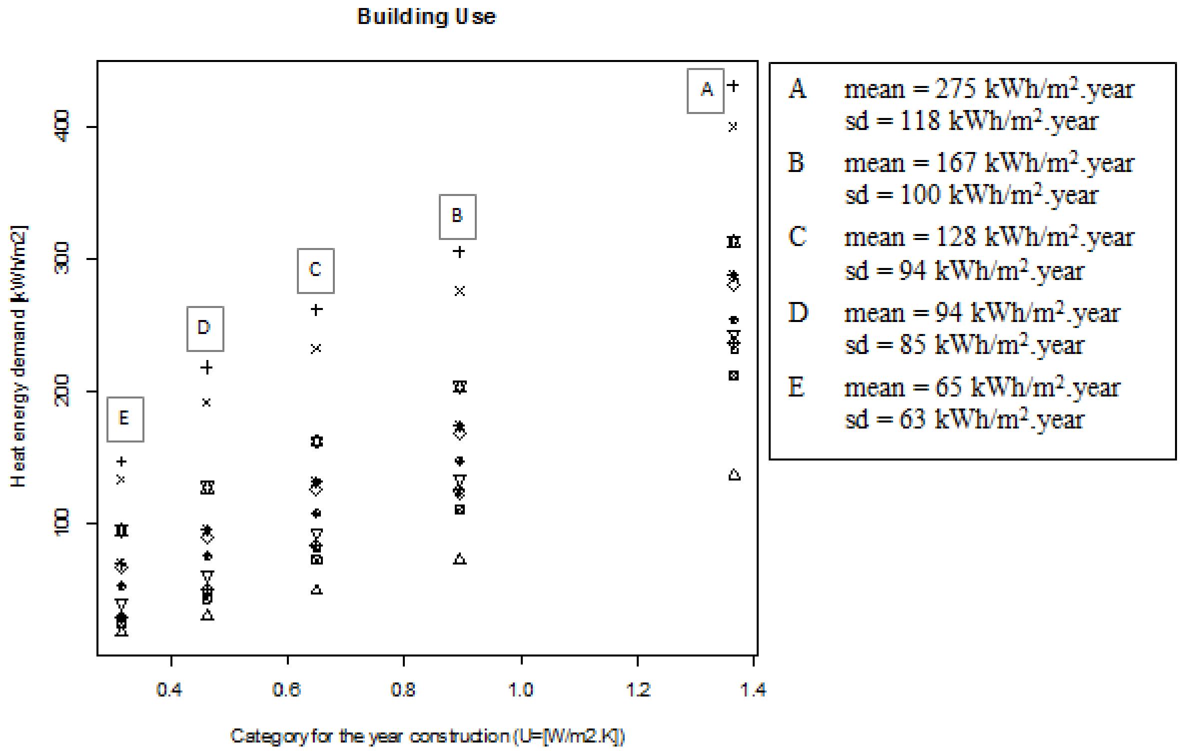

Figure 3 For each category A to E (represented by its total U-value) the left figure represents the annual energy demand of each building use (11 symbols) with the average and standard deviation over all 11 values given in the table on the right.

In order to confirm the choice and number of input parameter associated to each typology we produced a sensitivity analysis in the form of a design of experiments (DOE) for the following 6 input parameters: temperature set-point (over the interval[4]: 18, 19, 20, 21 and 22°C), total thermal capacity (0.1, 0.25 and 0.5MJ/m^2), glazing ratio (from 0 to 50% more than the default values given in figure 1), building orientation (from -90° to +90° relative to the default value of 0°, i.e. facing south), outdoor obstructions (obstructions on the horizon ranging from 0 to 90°) and weather conditions ("cold", "average" and "warm" years corresponding respectively to Meteonorm data for Verbier for an average year over the period 1961-1990 – with an average temperature of 5.4°C, for an average year over the period 2000-2009 – average of 6.4°C, and for Meteonorm's forecast for 2030 – average of 7°C). Table 1 displays the results of the design of experiments for categories in the unique case of a residential building use. It shows, for each category A to E, the percentage change (bottom row) relative to the reference value (top row) for annual energy demand, average power demand and maximum power demand for all 6 input parameters[5]. The sign of the percentage indicates whether increasing the value of the input has an increasing or decreasing impact on the simulation output with respect to the reference value.

The results clearly highlight the significant impact, for all categories A to E, of the temperature set-point, glazing ratio and outdoor obstructions on simulation outputs while weather conditions show little impact and building orientation none at all. The glazing ratio has the interesting property of significantly increasing heat demand for older buildings (due to high heat losses) while significantly decreasing heating demand in new buildings (thanks to increasing solar gains). Similarily thermal capacity is most

[4] The underlined value corresponds to the reference, i.e. the default value used for the typology.

[5] Non-representative values marked N/A result from the fact that the maximum power demand was limited by the nominal power entered as an input.

important for new buildings.

Table 1. Design of experiments for estimating the impact of input parameters on annual energy demand (E), average power (P) and maximum power (Pmax) demands.

	Temperature set-point			Total thermal capacity			Weather conditions		
	E [kWh/m²/a]	**P [W/m²]**	**Pmax [W/m²]**	**E [kWh/m²/a]**	**P [W/m²]**	**Pmax [W/m²]**	**E [kWh/m²/a]**	**P [W/m²]**	**Pmax [W/m²]**
A	231	50	83	231	50	83	231	50	83
	20%	6%	7%	-9%	6%	2%	-5%	2%	-2%
B	122	37	58	122	37	58	122	37	58
	22%	5%	7%	-16%	8%	2%	-8%	-3%	-2%
C	81	29	45	81	29	45	81	29	45
	23%	7%	7%	-17%	10%	2%	-9%	-3%	-2%
D	49	23	35	49	23	35	49	23	35
	24%	9%	9%	-20%	9%	3%	-8%	0%	-3%
E	29	16	28	29	16	28	29	16	28
	28%	6%	11%	-21%	6%	4%	-10%	0%	-4%

	Glazing ratio			Building orientation			Outdoor obstruction		
	E [kWh/m²/a]	**P [W/m²]**	**Pmax [W/m²]**	**E [kWh/m²/a]**	**P [W/m²]**	**Pmax [W/m²]**	**E [kWh/m²/a]**	**P [W/m²]**	**Pmax [W/m²]**
A	231	50	83	231	50	83	231	50	83
	N/A	N/A	N/A	0%	0%	0%	45%	-6%	-2%
B	122	37	58	122	37	58	122	37	58
	30%	70%	N/A	-1%	0%	0%	76%	-11%	-3%
C	81	29	45	81	29	45	81	29	45
	31%	83%	N/A	-1%	0%	0%	95%	-14%	-2%
D	49	23	35	49	23	35	49	23	35
	4%	83%	N/A	-2%	0%	0%	131%	-13%	-3%
E	29	16	28	29	16	28	29	16	28
	-31%	63%	N/A	0%	0%	0%	166%	-13%	0%

Based on these observations one could conclude that:

i. detailed information regarding the three dimensional layout of buildings within a city is of real importance in providing reliable simulation results (although the orientation of each building is of little significance and buildings can be simulated as facing southward with no significant loss in relevance of simulation results)
ii. as well as is information regarding the amount of glazing on exposed facades and whether buildings are attached or not,
iii. as the choice of the temperature set-point is significant this input parameter should take on a variety of values whose distribution needs to correspond to surveys of real values,
iv. the thermal capacity of a building should be well estimated (although three values representing “light”, “average” and “heavy” are enough) in particular for new buildings,
v. using averaged weather files of a particular site seem to suffice in providing reliable simulation results.

CONCLUSION

We present in this article a simple approach to simulating a large number of buildings at the level of a city neighbourhood or whole city based on the use of building typologies (caracterised by periods of construction and by building use) used in combination with a dynamical building simulation tool. The resulting hourly energy demand profiles can be used in combination with an energy production and distribution modelling tool (e.g. OSMOSE) or alone (e.g. when modelling building refurbishment measures) to propose a solution (system design and operation strategy) for meeting the thermal loads of an urban area in line with targets of the municipality's energy plan.

The success of this approach relies greatly on the appropriate choice of values for the simulation tool's input parameters. The sensitivity of the approach's results relative to the choice of periods of construction and building use in caracterising the building typologies as well as to the input parameters associated to the typologies highly depends on the case study to which it is applied, in particular on its climatic conditions, construction practices, typical building use (density of occupancy, profile of occupancy, installed electrical appliances) and the national building regulations that impact on these. We propose in this article a general methodology that the user can apply in order to fine tune the approach to their needs. For our specific case study, an alpine ski resort in Switzerland, we can conclude that our typologies – 5 categories of years of construction and 11 of buildings use – were well chosen. In addition we are able to recognize which input parameters require most attention. In our case study providing detailed information regarding outdoor obstructions, glazing ratios is paramount. Entering temperature set-points as well as information related to building use (internal heat gains and air exchange) that are consistent with real values is also important. Finally information related to the thermal capacity and (off average) outdoor temperatures are mostly relevant for newer buildings with lower heating requirements.

OUTLOOK

We have not discussed the clustering of single-building simulated energy demand profiles as this research is still in progress. A successful methodology will need to integrate the variability of real annual energy demands around the simulated average and the stochastic nature of energy demand. The research presented here will allow us to determine for which parameters an uncertainty analysis needs to be done. Stochasticity of demand will be integrated a posteriori by modifying simulated profiles of energy demand.

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Built Environment Sustainability Assessment of Poor Rural Areas of Southwest China

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ABSTRACT

Rural areas of China have rapidly developed throughout years. However, the development model of conventional rural modernization is not suitable for poor rural areas of southwest China, which is a mountainous area with scattered residents and very low development level. Unsustainable development has resulted in a series of environmental, social, and economic problems. This study reviewed the sustainable rural development theory, analyzed the development and construction situation of rural southwest China, and established an indicator framework of built environment sustainability assessment system for the poor rural areas of southwest China. This system has been established according to a new sustainable development paradigm that emphasizes endogenous development and suitability for rural southwest China. The system covered environmental, social, and economic dimensions of sustainability and considered natural and social conditions of rural southwest China. Case studies were conducted to validate the suitability of the new assessment index framework for poor rural areas of southwest China, and the capability of this index framework to recognize the various features of different cases. The outcome shows that the applicability and sensitivity of the new assessment index framework is better than the existing assessment systems in rural southwest China. This assessment framework can be applied to other similar rural areas.

1. INTRODUCTION

After the sustainable principle was applied in architecture in the 1990s, several countries and regions established building environment assessment systems. These assessment systems play a significant role in urban development because they provide standards or guidelines of building design, construction and management. However, most existing building environment assessment systems are established for urban areas, and are based on modernization development models. Some mountainous rural areas, such as rural southwest China are undergoing tremendous construction and development without appropriate guidelines and assessment systems. Copying the urban development model has led to serious problems in these areas. The lack of a suitable sustainable development model and the corresponding built environmental assessment system in these rural areas resulted in a problematic issue in China. This study aims to establish a framework of built environmental assessment system for poor rural areas of southwest China that is based on a suitable development model.

2. DEVELOPMENT AND ASSESSMENT SYSTEM OF RURAL SOUTHWEST CHINA

2.1. Status and problems of rural southwest China

Southwest China (Figure 1) is a mountainous and rivery area with dispersed population. This geographical pattern resulted in inconvenient transportation system that has seriously restricted the rural development of southwest China. Villagers face difficulty in to going outside for education, health care, purchasing, and trading. The conventional brick-concrete buildings and infrastructures are difficult to be built because of high transportation costs. At the same time, several unique minority cultures have been preserved in this area because of the closed living environment. However, these minority groups are relatively marginalized geographically and psychologically.

Figure 1 Southwest rural China

The social development level of rural southwest China has always lagged behind. It has been considered as one of the poorest regions in China. Almost half of the villagers have an educational level that is below junior secondary school. Unsafe water, poor sanitation, and inadequate health consciousness threaten human health. Moreover, southwest China is an area with frequent natural disasters. For example, earthquakes occur frequently in some areas of Yunnan and Sichuan. Other natural disasters, such as landslides and debris flow, happen often because of climate change and environmental degradation. Given the low disaster prevention and recovery capabilities, occurrence of natural disasters is another factor that causes poverty in rural southwest China.

To solve these problems and to maintain economic growth, China implemented the New Countryside Construction policies in 2005. The increased funding for rural infrastructure construction is mainly used for the construction of irrigation facilities, roads, water supply system, power supply system, communication system, and biogas. This type of top-down implementation is large-scale, fast, and effective. In some of the rural areas, which are nearby cities and have flat terrain, this modernization development model greatly improved rural life and urban-rural integration. However, this modernization plan is unsuitable for the mountainous poor rural areas. Problems emerged in this rural development process. For example:

- Modernization development model requires a considerable amount of inward investment that is difficult to sustain in rural southwest China.
- Top-down planning and construction work often lack enough public engagement, unable to meet the actual needs of villagers, and lead to a lack of cultural identity and sense of belonging.
- The timing and content of development have not been well organized to be consistent with the rural lifestyle. The original rural life has been disrupted. (Baoxing 2009)
- Traditional values are influenced by external factors. Local tradition and minority culture have disappeared because of the effects of modernization. People focus too much on to

financial capital.

- Neglecting sustainable development causes serious environmental damage.
- Rural industrialization requires start-up capital and long-term technical support that are not easily attainable for majority of poor rural residents.
- Although some of the rural houses have been rebuilt with industrial materials, people still cannot live a comfortable, safe, and affordable life because they cannot fully understand the design and construction technology of modern architecture. The building quality and performance are not satisfactory (Xiuyan 2008). Construction costs for these structures are higher than the costs to build local vernacular houses.

Under this circumstance, a considerable number of rural residents chose to be migrant workers in urban areas, which have left behind the aged and the children. Hence, these mountainous rural areas lose vigor and cohesive force, and became the accessories of urban areas and symbol of backwardness.

2.2. Existing built environment assessment systems of rural southwest China

Rural southwest China faces a series of problems in the process of development because the rural modernization development model is unsuitable for such mountainous areas. Therefore, rural southwest China needs an assessment system that could provide comprehensive understanding and guidelines for sustainable construction and development. Currently, only three standards relate to rural built environment in mainland China (Table 1). The Hygienic Standard for Rural Housing and the Hygienic Standard for Rural Household Latrine (MOHC 1998, MOHURD and AQSIQ 2003) mainly focus on sanitary conditions. In 2006, the Ministry of Environmental Protection of China established the National Eco-village Creating Standard (NCES) to encourage the creation of eco-villages. This standard considered economic, sanitation, pollution control, resource, sustainable development, and public participation issues. NCES covers a broader range of rural development. However, it is a very simple standard that contains only 16 indicators, and thus, the consideration of architecture-related issues are not enough (MEPC 2006). A comprehensive built environment sustainability assessment system for rural southwest China is needed.

Table 1. Standards related to rural built environment in mainland China

No	Standard / Assessment System	Published	Institution
1	Hygienic Standard for Rural Housing	1988	Ministry of Health of China (MOHC)
2	Hygienic Standard for Rural Household Latrine	2003	Ministry of Housing and Urban-Rural Development (MOHURD) and Administration of Quality Supervision, Inspection and Quarantine (AQSIQ)
3	National Eco-village Creating Standard	2006	Ministry of Environmental Protection of China (MEPC)

3. BUILT ENVIRONMENT SUSTAINABILITY ASSESSMENT OF RURAL SOUTHWEST CHINA

3.1. Sustainable development model for mountainous rural areas

In Europe and other developed countries, the critique of rural modernization, which focuses on the problems of over-production, environmental degradation, and spatial inequality, has been proposed as early as the 1970s. Thereafter, a new rural development paradigm that is different from the modernization paradigm has been proposed. First, this paradigm shifted the development emphasis from "inward investment" to "endogenous development". Second, the mode of delivery for rural development has shifted from a "top-down approach" to a "bottom-up model". Third, the structure of rural development policy has moved from "sectorial modernization" to "territorially based integrated rural development”. Table 2 summarizes the other key points of the new rural development paradigm.

Table 2. Features of the modernization paradigm and the new rural development paradigm (Woods 2011)

Modernization paradigm	New rural development paradigm
Inward investment	Endogenous development
Top-down planning	Bottom-up innovation
Sectoral modernization	Territorially based integrated development
Financial capital	Social capital
Exploitation and control of nature	Sustainable development
Transport infrastructure	Information infrastructure
Production	Consumption
Industrialization	Small-scale niche industries
Social modernization	Valorization of tradition
Convergence	Local embeddedness

Under this new rural development paradigm, rural development should be based on the local bio-capacity and cultural context. The rural endogenous development strategies focus more on food localization, traditional craft industries resurrection, sustainable exploitation of resources, and social capital improvement. Different from the modernization paradigm, the new rural development paradigm compensates for the inconvenient transportation and insufficient financial capital, makes full use of local resources, limits environmental impact, respects local culture, and benefits human development. Obviously, this paradigm is more appropriate for poor rural areas of southwest China, which have inconvenient transportation and low development level. It can improve the quality of rural living environment, maintain the vigor and cohesive force of the mountainous poor rural areas, and increase life control of the rural residents. Rural areas can then be attractive places like urban areas.

In the definition of sustainable development, “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, “human needs” comprise the core issues of sustainability. According to Maslow’s hierarchy of needs theory, the basic needs of humans have five levels: physiological needs, safety needs, love and belonging needs, esteem needs, and self-actualization needs. Among these levels, the first two needs are basic human needs, and the other three are psychological needs (Maslow 1943). In southwest China, sustainable rural development based on the new rural development paradigm means that the basic human needs should be met based on the local conditions and resources. Then, comfortable and sustainable environment should be provided to meet human psychological needs. Therefore, two levels of sustainable rural development should be implemented in southwest China:

- First, to reduce reliance on outside resources and improve ability of life control and risks resistance, the basic human needs should be met without external support and environmental damage. Thus, self-reliance must be achieved in basic human needs under existing bio-capacity.
- Second, to provide a sustainable environment to meet the human psychological needs, the natural environment should be recovered, bio-capacity should be increased, and development capability should be improved.

3.2. Built environment sustainability assessment of rural southwest china

A Rural Built Environmental Sustainability Assessment System (RBESAS) should be established for poor rural areas in southwest China. Different from urban areas, the scope of rural built environmental sustainability assessment should include buildings and other infrastructures, public spaces, farmlands, and so on. The reason for considering the entire built environment is that the rural settlement is an organism comprising of humans and the environment. The building is not the most important part of this organism. Rural residents do not spend as much time in buildings as urban residents do. The sustainability of a ural settlement is more related to the community and surrounding environment. Therefore, in this study, the built environment of poor rural areas of southwest China includes several components:

- Buildings (residential buildings, public buildings, etc.)
- Infrastructures (transportations, communications, power supplies, water supplies, markets, squares, landscape, etc.)
- Production facilities (farmland, livestock pens, etc.)

According to the two levels of sustainable rural development previously mentioned, the criteria of RBESAS should be divided into two parts:

- Self-reliance capability: To meet basic human needs without over reliance in outside resources under existing bio-capacity, and at the same time, does not reduce bio-capacity.
- Development capability: To increase the bio-capacity, and to meet human psychological needs for better development.

Thus, the built environmental sustainability of poor rural areas of southwest China can be described as follows (Figure 2):

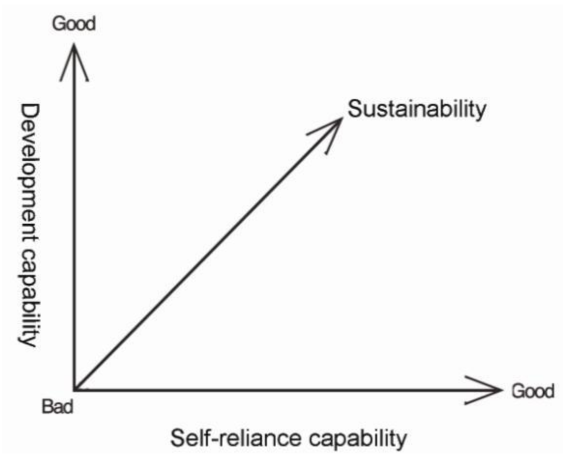

Figure 2 Built environmental sustainability of poor rural areas

Table 3 summarizes the relationship between rural development sustainability and rural built environment.

Table 3. Rural sustainability and rural built environment element matrix

<table>
<tr><td colspan="3" rowspan="2"></td><td colspan="3">Rural built environment</td></tr>
<tr><td>Buildings</td><td>Infrastructures</td><td>Production facilities</td></tr>
<tr><td rowspan="4">Rural built environmental sustainability</td><td rowspan="2">Self-reliance capability</td><td>Biocapacity protection</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>Self-reliance on basic human needs</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td rowspan="2">Development capability</td><td>Ecology improvement</td><td></td><td>●</td><td>●</td></tr>
<tr><td>Meet the psychological needs of human</td><td>●</td><td>●</td><td></td></tr>
</table>

According to the matrix of rural development sustainability and rural built environment element, a framework on issues and indicators can be established (Table 4).

Table 4. Framework of RBESAS indicators

RBESAS	Self-reliance capability	1. Land & resources conservation	1.1 Sensitive areas conservation 1.2 Agricultural land conservation 1.3 Soil and water conservation
		2. Waste management	2.1 Construction & demolition waste management 2.2 Operation waste management
		3. Pollution control	3.1 Pollution-free construction & demolition 3.2 Pollution-free agriculture
		4. Food self-reliance	4.1 Local food production 4.2 Diversified farming
		5. Water self-reliance	5.1 Water quality 5.2 Water efficient irrigation 5.3 Water efficient buildings & appliance 5.4 Water reuse
		6. Housing self-reliance	6.1 Regional materials 6.2 Efficient use of materials 6.3 Indoor environmental quality 6.4 Housing affordability
		7. Safety and security	7.1 Settlements location 7.2 Safety and security design
		8. Health & well-being	8.1 Living environmental sanitation 8.2 Community basic services 8.3 Community recreation facilities and open spaces
		9. Energy self-reliance	9.1 Embodied energy of materials 9.2 Energy efficient buildings & appliance 9.3 Local & renewable energy
		10. Economic self-reliance	10.1 Local economy improvement 10.2 Activation & empower
	Development capability	11. Sustainable landscaping	11.1 Biocapacity improvement
		12. Sustainable agriculture	12.1 Circular agriculture 12.2 Biological controls
		13. Culture & context	13.1 Protection of historical & cultural heritage 13.2 Keep local characteristics 13.3 Coordination with natural environment
		14. Inclusiveness & participation	14.1 Barrier-free facilities 14.2 Public engagement
		15. Education & information	15.1 Education space and facilities 15.2 Information facilities

The issues of this system can be divided into two parts: self-reliance capability and development capability. The self-reliance capability category includes 10 issues. Issues 1, 2, and 3 consider environmental conservation and pollution control which aim to avoid environment damage and bio-capacity reduction. Issues 4, 5, and 6 involve self-reliance of human physiological needs. Issues 7, 8, 9, and 10 include self-reliance of human safety needs. The development capability category includes five issues. Issues 11 and 12 consider environmental recovery and bio-capacity enhancement. Issues 13, 14, and 15 focus on the improvement of rural built environment concerning the human needs of love and belonging, esteem and self-actualization. This system considers both environmental protection and human development needs in the poor rural areas of southwest China. At the same time, the system includes all the three dimensions of sustainability, which makes it a relatively comprehensive built environmental sustainability assessment system.

3.3. Case study

To validate whether the RBESAS index framework is appropriate to poor rural areas of southwest China, three cases will be analyzed by the existing NECS for rural China and RBESAS index framework. Comparative study will be done on three cases, which have different characteristics (Figure 3).

Case I is a typical traditional village that possesses most of the typical limitations, such as low income, poor infrastructure facilities, and uncomfortable living environment. It is highly relies on local resources, but the development is very slow. Many villagers have decided to find employment in urban areas for better income. Therefore, the old village is losing vigor and cohesive force.

Case II is a typical top-down rebuild village that is run by local government after a huge earthquake in 2008. Reconstruction followed the modernization paradigm of rural development. The infrastructure of this village has been improved, but the increased construction cost added immense burden to the villagers. The brick-concrete house is not energy efficient because of the use of materials with high embodied energy and the lack of bio-climatic design. The function and special design are not suitable for rural life because of inadequate public engagement.

Case III is a post-earthquake demonstration reconstruction project that follows the concept of sustainable development. Local traditional building technology has been innovated to improve seismic performance and indoor environmental quality as well as to maintain energy and cost efficiency. Rural infrastructure and sanitation condition have been improved to provide better living environment. Villagers were fully engaged and empowered during the cooperation of reconstruction. This project also won several awards in China and abroad (Li, Ng et al. 2011).

Figure 3 The three cases in southwest China

The three cases are checked by indicators of the NECS and the RBESAS. The outcome shows the number of indicators applicable and not applicable for the cases. Among the applicable indicators, the number of requirements that can be achieved by the cases and those that cannot be achieved is determined (Table 5). Therefore, the study concludes with the number of indicators of each system that are suitable for these cases, and whether each system can identify the advantages and disadvantages of the different cases.

Table 5. Analyze outcome

	Case I	Case II	Case III
NECS	Applicable: 62.50% Unsatisfied, 12.50% Satisfied; Not applicable: 25.00%	Applicable: 56.25% Unsatisfied, 18.75% Satisfied; Not applicable: 25.00%	Applicable: 50.00% Unsatisfied, 25.00% Satisfied; Not applicable: 25.00%
RBESAS	Applicable: 45.95% Below average, 51.35% Above average; Not applicable: 2.70%	Applicable: 62.16% Below average, 35.14% Above average; Not applicable: 2.70%	Applicable: 24.32% Below average, 72.97% Above average; Not applicable: 2.70%

The analyzed outcome shows that the applicability of the NECS in poor rural areas of southwest China is relatively low. A quarter of the indicators are not applicable to these cases. RBESAS showed great superiority in the applicability of these cases. Almost all RBESAS indicators are applicable for the case villages because this indicator framework has been established according to the existing situation of rural southwest China. The system considers the entire built environment, including buildings, infrastructures, and production facilities.

On the other hand, the sensitivity of the NECS is relatively low. According to the assessment outcome, the performance of Case I is the poorest. Case II is slightly better than Case I, and Case III is slightly better than Case II. However, the difference among these three cases is relatively minimal. All the three cases are unable to meet more than 50% of the indicators. The RBESAS can distinguish clearly the different advantages and disadvantages of the three cases and recognize well the significance of endogenous development model. The outcome of analysis shows that the sustainability of Case I is slightly better than Case II because the latter has less consideration on energy and economic self-reliance, local culture, and public engagement. The sustainability of Case III is better than Cases I and II. Case III improved rural living environmental quality without posing damage on the environment and entailing high costs, and preserved the local culture. Moreover, villagers felt that they are the real masters of their home land because they were fully engaged and empowered during the reconstruction.

4. CONCLUSIONS

Having a comprehensive understanding of built environmental sustainability of poor rural areas is one of the significant steps to solve the problems between rural development and environmental conservation in southwest China. The results of this study show that RBESAS provides an appropriate indicator framework of built environmental sustainability assessment system for poor rural areas of Southwest China. First, this framework was established based on the concepts and theories of sustainable rural development and sustainable architecture. Second, scope and issues of this system were established according to the existing situation of poor rural areas of southwest China. These ideas ensured the scientificity and adaptability of the assessment system, and were more suited for rural areas that follow the endogenous development mode. RBESAS indicator framework also appropriate to other rural areas which follows sustainable development paradigm. More specific research needs to be done to identify evaluation method of each indicator according to local situation of different rural areas.

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Session 4A : Passive Design

PLEA2014: Day 2, Wednesday, December 17
8:30 - 10:10, Auditorium - Knowledge Consortium of Gujarat

Climate-responsive Vernacular Swahili Housing

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ABSTRACT

Vernacular architecture is manifested by a large variety of forms that have a diversity of explanations. This arises from the idea that people of different backgrounds and cultures respond differently to wide-ranging physical environments and the interplay of socio-cultural factors. In this paper, the authors introduce the development of Swahili architecture in Kenya as a response to warm-humid climate. Initially, to encapsulate generic design recommendations for this climate, bio-climatic design responses were derived using Mahoney Tables analysis and reinforced by guidelines obtained from previous research. This revealed conspicuously supportive arguments for lightweight air-permeable buildings in contrast to the existing Swahili form that is noticeably heavyweight. An exploration of the influence of socio-cultural factors and building materials enabled the authors to explain how these and other factors may have masked or overridden the sole effect of climatic parameters resulting in the heavyweight typology. Further, field study investigations of a series of Swahili buildings in Mombasa were conducted during the warmest periods of two years. In this paper the authors focused on the findings from the investigations of one of those buildings. Results showed indoor temperatures lower than corresponding outdoor temperatures by up to 7°C during peak times. Additionally, an occupancy survey conducted during the study periods found that up to 70% (during the warmest months) and 99% (during the coolest months) of the occupants found the studied building thermally comfortable. These analyses of the environmental response of this architectural typology revealed the suitability of plan, form and fabric characteristics. It was concluded that vernacular Swahili housing could offer insights into a different and valid approach for design of passive contemporary buildings within the local warm-humid climate.

Keywords: Swahili architecture, heavyweight architecture, climate-responsive design

INTRODUCTION

Steeped in history, the East African coast covers the coastal region of Kenya, Tanzania and Mozambique. The region developed largely as a result of trans-oceanic trade with Arabs and Indians that was facilitated by alternating monsoon winds. This led to the establishment of a number of coastal towns whose inhabitants share history, language and cultural traditions of which some scholars claim to date to at least 100A.D (Ghaidan, 1975). The lifestyle of the immigrants combined with the impact of their religion, Islam, and much else of their tradition, had a strong influence on the local inhabitants. This interaction eventually resulted in a distinctive cultural mix referred to as 'Swahili' (Oliver, 2007). As a result, there evolved in these coastal cities, a civilization having a character of its own, not least in respect of its architecture. Today, the region continues to thrive as a trade and transport hub.

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WARM – HUMID CLIMATE

This climatic region is located between 15° North and South of the equator. Major cities found within this region of Kenya include Mombasa and Lamu, both of which showcase a rich heritage of Swahili architecture. Little seasonal variation is experienced with no distinct seasons apart from instances of heavy or light rain - slight differences may arise from variations in altitude and exposure. Annual temperature averages range from 27°C to 32°C (daytime) and 21°C to 27°C (night-time) with on and off shore breezes occurring throughout the day. Humidity levels range from 55% to 100%, and with an annual average of 75% (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974, p. 26). Due to the regional proximity to the equator, the sun is almost always directly overhead resulting in high radiation intensities, especially at the zenith and the western orientation.

Recommended architectural responses in Warm-Humid climate

A review of past building trends in warm-humid climates for a significant period of the 20th century reveals that the widely accepted house type was lightweight and elevated on stilts so as to enhance full cross ventilation – much like the traditional Malay house type (see Figure 1). The typology showed quick thermal response and would cool down rapidly after sunset while exploiting breezes to offer relief to occupants (Koenigsberger et al., 1974; Szokolay, 1996).

Using the 'Mahoney tables' design aid, as introduced by Koenigsberger et al. (1974), recommended bio-climatic design strategies were derived using recorded climate data for Mombasa. This analysis revealed main design recommendations as illustrated in Figure 2. Results revealed a typology that is principally lightweight. It works on the premise that: since the temperature differences between the outside and inside show little variation, the only substantial relief that can be gained by users is from air movement for physiological cooling.

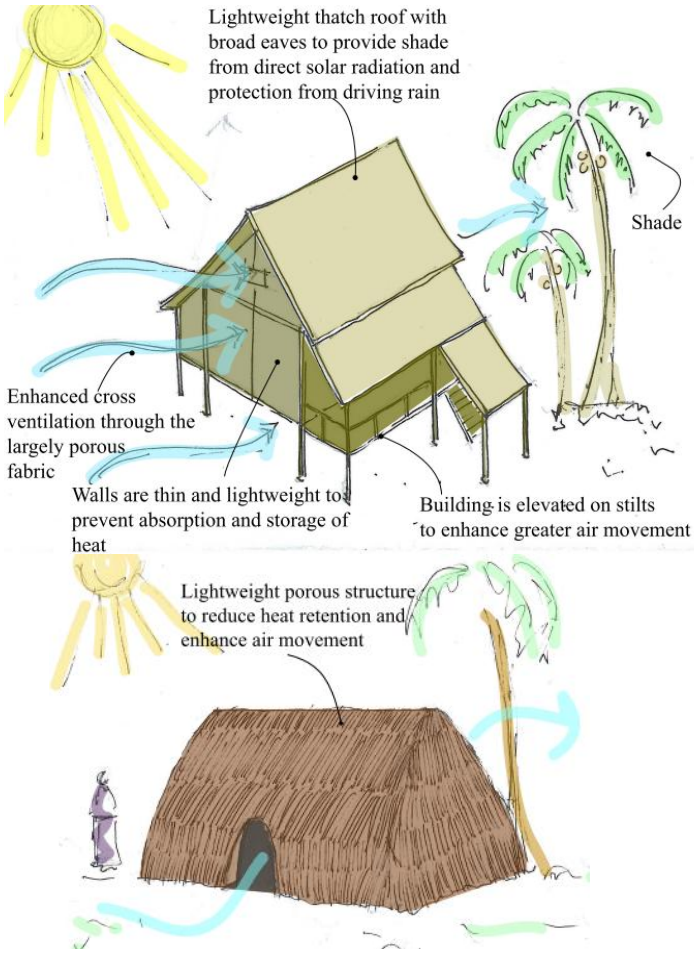

Figure 1 Examples of building types found in warm humid climate regions Top: Traditional Malay house, Malaysia. Bottom: Mijikenda house, Kenya (images produced by the authors).

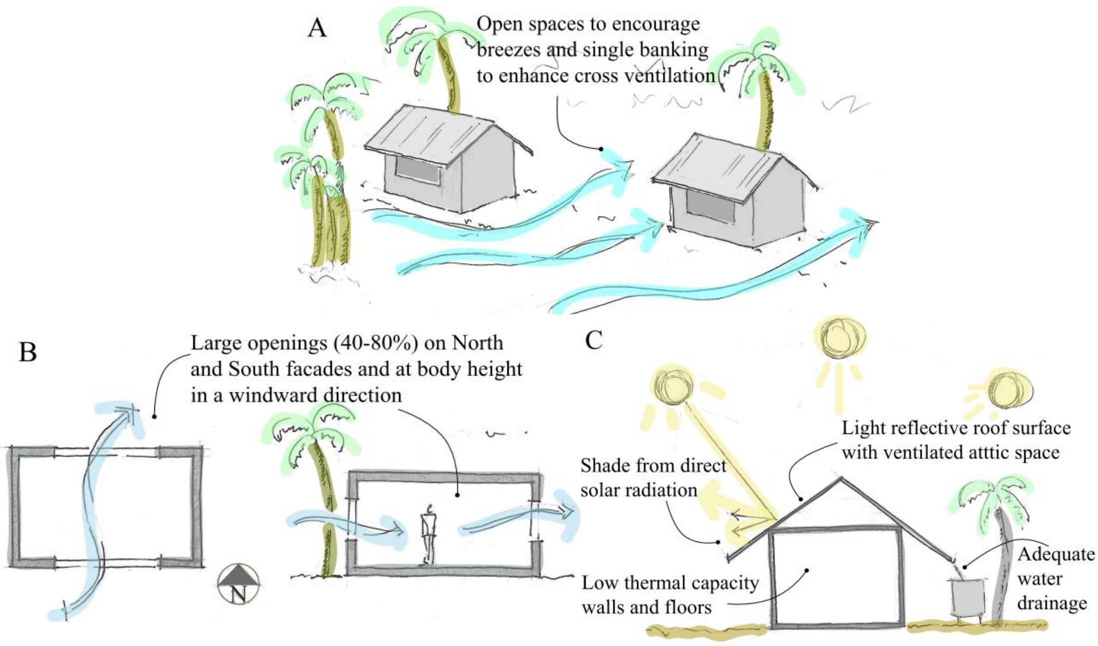

Figure 2A, B and C: Recommended design strategies for warm humid climates (images produced by the authors).

SWAHILI ARCHITECTURE

The predominant building type is the Swahili house - usually a one, two, or three storey structure set in irregular rectangular plans as shown in Figure 3. Much unlike the aforementioned lightweight typology, it is characterized by heavyweight structures made of thick coral rag walls, timber framed doors and windows, timber balconies and flat coral rag or pitched palm leaf frond roofs (more recently, these were replaced with galvanized iron roofing sheets).

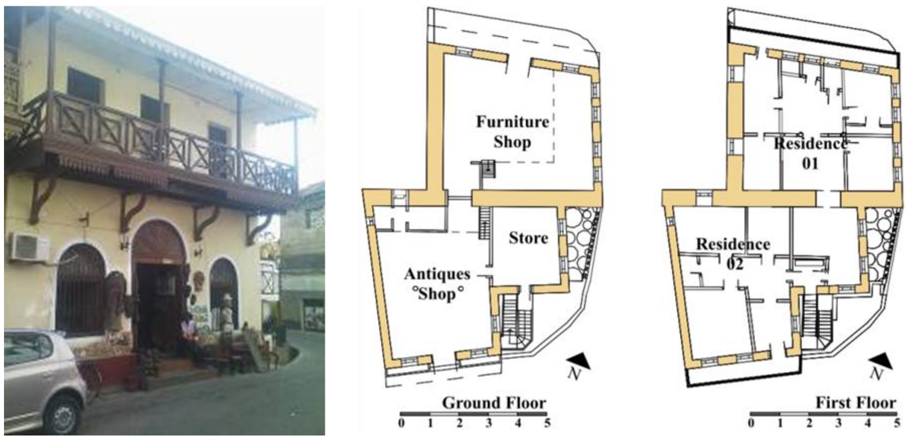

Figure 3 A view of the selected two storey Swahili house (Old Post Office) in Mombasa, Kenya (images from/produced by the authors).

It has been suggested that form is not merely as a result of physical constraints or individual factors, but rather the effect of an entire range of socio-cultural factors, modifications by climate and the availability of materials and technology (Rapoport, 1989). Indeed, initial analysis revealed that the Swahili house manifests a complex interaction of various factors that could be responsible for this deviation from the expected lightweight typology. It is suggested that without compromising on the aesthetics, physical and social functionalities, this architectural type was adapted to fit into the milder warm humid climate. An examination of these influences sought to explain how they may have worked towards creating Swahili architecture as we know it.

Socio-cultural Influence

It has been noted that Swahili architecture borrowed heavily from that of the hot-dry architecture of the Arab world as a direct result of cultural integration (Ghaidan, 1975; Mombasa Municipal Council & National Museums of Kenya, 1995). Indeed, the Islamic heritage of the Swahili people is strongly manifested in their architecture through the form and spatial arrangements of their settlements. Writing on the Swahili concept of space, Ghaidan (1975) suggested that spatial organisation is culturally determined. As is typical of Islamic settlements, aspects of privacy are significant and evident in use of screens and the 'inward' organisation of space. Owing to the strict requirements for visual and acoustic privacy it seems highly unlikely that the prescribed lightweight solution would have been deemed socially acceptable. Also, this might explain the prominence of architectural elements such as screened balconies/windows and courtyards which not only enhance privacy through provision of semi-private outdoor spaces but also promote shading and cross ventilation.

In older settlements such as Lamu, buildings were primarily double storied and used mainly for residential purposes (Oliver, 1997). In more recent Swahili settlements such as those in Old Town, Mombasa there is a slight variation to this plan; commercial activities are on the ground floor and living spaces on the top - resulting in a mixed-use building (Mombasa Municipal Council & National Museums of Kenya, 1995). Also evident is the use of ornate architectural elements for aesthetic purposes. This is apparent in the use of ornately carved doors, highly decorated balconies and decorative frieze motifs (figurative representations are rare due to the discouragement of imagery in art by Islam).

Climatic Influence

The typical Swahili town consists of an irregular maze of buildings arranged in dense clusters with streets measuring an average of 1.5 to 6 metres wide and punctuated by a series of open spaces, as shown in Figure 4. Climate analysis revealed that the air temperature in warm humid climates is almost always very near to that of skin temperature. This leaves sensible air movement as the main means of relief through physiological cooling. In response, the streets - considered to be public living rooms and constantly abuzz with activity - are laid out to channel cooling sea breezes, as is the case in Mombasa and Lamu (Ghaidan, 1975). Subsequent work by Deogun, Rodrigues, and Guzman (2013) and field studies conducted by the authors reveals this to be a logical assumption.

Aspects related to enhanced air movement and solar sun shading appeared to be the main strategies showcased in Swahili houses. As air movement is essential to cope with the humid heat, elements such as screened balconies, window shutters and courtyard spaces were used to facilitate effective cross ventilation and thermal regulation. Additionally, narrow streets and alleyways, balconies and small enclosed courtyards played a big role in mitigating high intensity solar radiation as illustrated in Figure 5. By closely aligning the buildings, mutual shading worked by the heat transfer potential through the external walls. Similarly, balconies and window shutters worked as sun shading elements by screening of direct sunlight and prevention of glare. For open spaces, vegetation was used to shield direct solar radiation. To lower the impact of direct solar radiation, it is advisable for buildings along or near the equator to be laid out with the shorter sides facing East and West. However, mainly due to the need to channel breeze or due pre-existing street layout constraints, this was not always possible. To counter this, walls would be effectively shaded to minimise direct insolation as explained earlier. In addition to this, the reflective qualities on the outer surface of the white lime washed walls also helped reduce the impact of incident solar radiation.

The typical Swahili house is relatively deep, has thick walls and roofs and single or double banked rooms. In hot dry climates, use of a heavyweight walls and roofs is valid as the warmth accumulated in the thick fabric is dissipated during the significantly colder nights. In warm-humid regions, heavyweight walls act by minimising heat conductivity potential. Despite the slightly warmer night temperatures, heat that builds up in the heavy fabric during the day may still be dissipated by facilitating air movement during the night or during periods of cooler outdoor temperature - done mainly by opening of windows. Also, where houses had flat coral rag roofs, most were eventually covered with a pitched roof with open gable ends (Oliver, 1997), thereby creating an attic-type space that effectively reduced the impact of direct solar radiation at the zenith. In Swahili houses, windows had integrated shutters that could be opened and adjusted as necessary to encourage air movement and heat dissipation (see Figure 6). To improve occupant comfort, windows were located at body level and could be up to 2.1 metres in height. Occasionally, the buildup of temperature and humidity indoors may result in an increase above outdoor conditions. However, when the outdoor temperatures are cooler, the shutters could be opened to allow for a comforting breeze. Similarly, the screened balconies would provide zones where one could enjoy the benefit of the sea breeze.

Figure 4 Left: Sectional plan of Old Town, Mombasa. Centre: Children play within one of the open spaces. Right: Ndia Kuu Road, one of the narrow streets - note the mutual shading of buildings (Plan is author-modified from Google Earth, images from the authors).

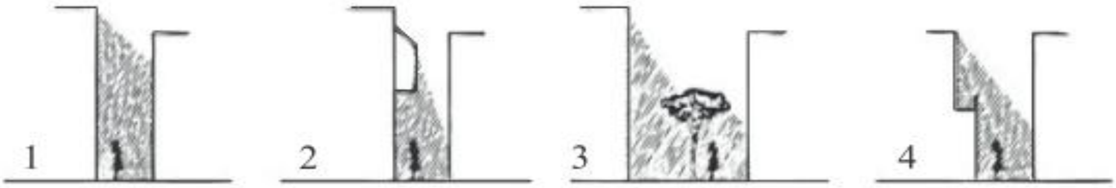

Figure 5 Shading configurations found in a vernacular Swahili setting (images from the authors).

Figure 6 A typical vernacular Swahili house (Old Post Office) showing A: a screened balcony and B: Window shutter C: Sketch of a typical window in use (images from the authors).

Materials and Construction Influence

Records indicate that earlier settlements had houses made of palm fronds, mangrove poles and wattle, and mud brick. With the onset of immigration, one was held in higher esteem if they owned a 'stone' coral house (Ghaidan, 1975). Correspondingly, as benefitted by its readiness of availability and usability, coral became a major building material on the East African coast. It is available in two varieties: hard terrestrial coral and soft reef coral, used for structural and non-structural purposes, respectively. As is still done in some places today, the coral was burnt to provide the lime for mortar and plaster. The coral walls were made to be notably thick, ranging between 440 to 560mm thick (Ghaidan, 1975, p.24). Field studies by the authors have found evidence of walls of up to 700mm thick in the Old Post Office building that would be able to provide a time-lag of up to 8.5 hours (Kiamba, 2010a). This facilitates delay of peak indoor temperatures thus extending periods of thermal comfort indoors.

As mentioned earlier, in more recent settlements, roofs are made of locally available mangrove poles with palm leaf fronds or galvanized iron sheets with an attic below. Externally, carved doors and intricately designed balconies enhanced the facades. Inside, the use of niches, carved into the walls for display of items and decorative friezes on the plasterwork were used to enrich the interior spaces.

ENVIRONMENTAL RESPONSE

Despite the fact that the Swahili typology (see Figure 7) is a deviation from the lightweight norm, further research has indicated that closely packed heavyweight buildings are potentially feasible for warm humid climates. The basis behind this premise is that the heavyweight buildings which are mostly closed up during the day would allow for significantly lower solar heat gains. At night, they would then be opened up to allow for sufficient cross ventilation that would in effect get rid of stored heat. Szokolay (1996) suggests that the inherent thermal capacity of the heavyweight structure facilitates heat storage, release and dissipation as opposed to a lightweight structure that closely follow outdoor temperature variations. Related studies by Tenorio (2002) reached a similar conclusion.

In an initial field study, temperatures of up to 7°C below that of corresponding outdoor temperatures were recorded during peak outdoor temperature times within a typical vernacular Swahili building (Old Post Office). Further analysis through computer simulations confirmed this reduction in temperature swings inside the house (Kiamba, 2010a, 2010b). This suggested that the heavyweight construction had a significant impact on indoor conditions, especially during the warmest hours of the day. Figure 8 shows corresponding indoor and outdoor daily temperatures recorded on the ground floor of the Old Post Office building, during the initial study period in March, 2010 (Records over the last 50 years indicate that the warmest month of the year in Mombasa is usually March). In a subsequent and substantially longer period of study undertaken in March, 2014 (see Figure 9) corresponding indoor and outdoor daily temperatures recorded in the same location and building show a similar trend. The lower (daytime) and generally more stable indoor temperatures were suggested to be due to thermal inertia provided by the heavyweight fabric and solar sun shading that effectively reduced the rate of and amount of heat gain absorbed. Also, air movement through screened openings not only provided physiological cooling for occupants but also promoted indoor heat dissipation through cross-ventilation.

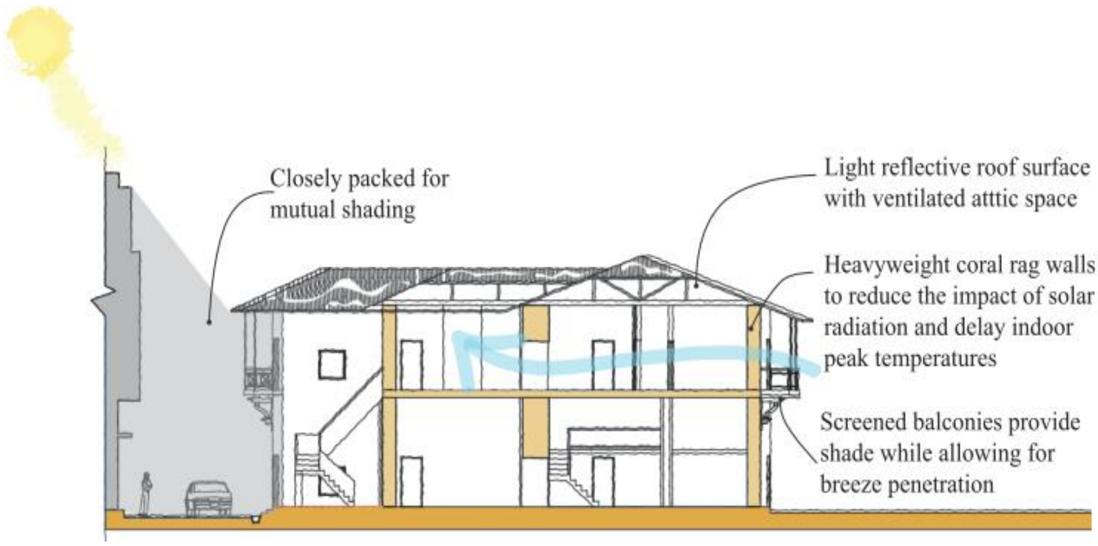

Figure 7: How a typical vernacular Swahili house (Old Post Office) works (image produced by the authors).

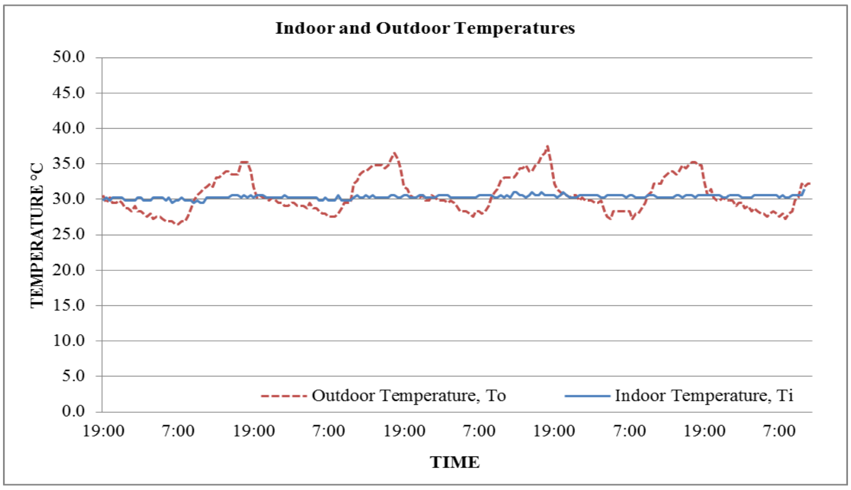

Figure 8 Recorded temperatures for corresponding indoor (Ti) and outdoor (To) temperatures for a typical Swahili house (Old Post Office) in Mombasa (graph produced by authors).

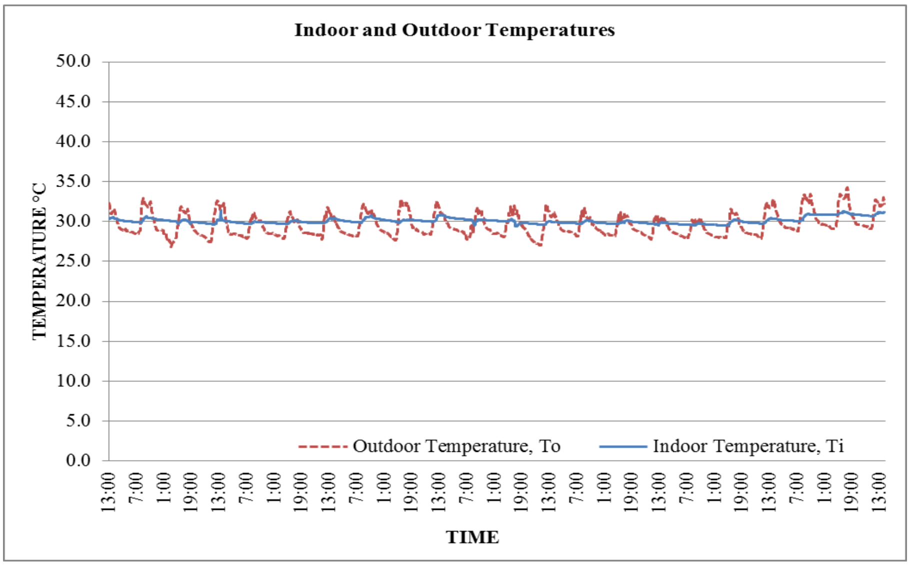

Figure 9 Recorded temperatures for corresponding indoor (Ti) and outdoor (To) temperatures for a Swahili house (Old Post Office) in Mombasa (graph produced by authors).

A post occupancy study was undertaken to determine occupant satisfaction levels, including that of thermal comfort, within the building. The respondents consisted of 10 occupants, both male and female, ranging from 55 to 18 years of age, of generally good health and who were accustomed to warm-humid tropical climatic conditions. Typically, occupants had a metabolic rate ranging from 0.7 to 1.6 met and a clothing insulating value of less than 0.6 clo. It was established that up to 70% of the occupants found the building thermally comfortable and satisfactory during both periods of field study (conducted during the warmest time of the year) and up to 99% during the cooler months. For 95% of occupants, access to ventilation controls (primarily windows) was satisfactory and enabled them to adjust indoor conditions as required. As the building is naturally ventilated all year round, air movement is largely dependent on channeling of breezes. Whereas mechanical fans were installed in the late 1970s, occupants noted that they preferred not to use them, citing that the incoming sea breeze was adequate. Indeed, the authors found that it was quite pleasant to sit by the windows or in the balconies as one would experience a refreshing sea breeze, especially in the afternoons. Occupants indicated that the only time fans tended to be used was if there was an increase in the number of users of a space, and even then, mainly in the afternoon period in the warmest periods of the year. During the study, recorded outdoor air velocity was almost always greater than 0.25m/s with monthly averages of approximately 3.7m/s. Similarly, indoor air velocity measurements varied with recordings of 0.2 to 2m/s measured at window openings with higher readings in the afternoons, indicating that air movement levels could possibly have aided comfort.

CONCLUSION

Swahili houses serve as an example of a vernacular typology that developed as a result of the interplay of social-cultural and physical factors. An analysis of these factors has shown how this seemingly 'out of place' architecture came to be influenced by its interactions over a long period of time. In the initial part of the study, design recommendations were found to pointedly recommend a lightweight solution that capitalises on low thermal capacity and the physiological cooling effect of sensible air movement to make higher temperatures acceptable to users. On observation, Swahili architecture was found to be the anti-thesis of this strategy as it is densely packed, notably heavyweight and with comparatively fewer and smaller openings. Initial analysis suggests that the Swahili house exhibits a potentially suitable architectural and environmental response to the local context and climate. Identified design strategies included the use of:

1. Heavyweight building fabric to reduce the impact of solar radiation.
2. Mutual shading of the 2 to 3 storey high buildings to mitigate heat gain.
3. Pitched roof with a ventilated attic space to reduce impact of solar radiation at the zenith.
4. Screened balconies and shuttered windows to promote thermal regulation by channeling breezes and sun shading while meeting requirements for acoustic and visual privacy.
5. Light coloured envelopes enhanced reflective capabilities of exposed wall and roof surfaces.

Having thrived over centuries, Swahili architecture is manifested by a distinct typology that enriches the fringe of the East African coast. Even so, with increasingly rapid urbanization and the influence of 20th century modern architecture, cities in the region continue to grapple with deterioration of their built environment. This 'newer' and mainly lightweight architecture has been marked by the introduction of active measures that are costly and unsustainable. This has created the need to find viable climate responsive design alternatives. It is possible that implementable solutions lie in the architecture of vernacular Swahili housing - this paper is the start of this investigation. Although initial investigations suggest that the typology in combination with the aforementioned strategies is potentially an appropriate strategy in moderating the impact of the external climate on indoor conditions, further analysis is currently underway to outline in greater detail the suitability of this approach to warm-humid climate.

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Integrated Environmental Assessment of Hemocentro Ceara (Blood Center): Sustainability and Space Quality Guidelines

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ABSTRACT HEADING

The inclusion of sustainability and humanization in Health Care Facilities is critical for the welfare of staff and users. These elements are part of rehabilitation programs undertaken by the Ministry of Health of the Brazilian Federal Government, in partnership with the University of Brasilia, developed by the Laboratory for Applied Sustainability to Architecture and Urbanism, LaSUS, for the network of blood centers in Brazil. In this sense, this article discusses the presentation of the methods used in integrated environmental assessment of the building from the Blood Center of Ceará (HemoCE) to improve environmental quality and energy use of the building. Results obtained confirm the validity of these integration methods in the construction of guidelines for the rehabilitation design of the building, in order to enhance environmental quality and humanization of space. Finally, through the guidelines identified for the HemoCE building, intervention solutions were proposed for specific areas, according to its peculiarities, as well as for the building as a whole, based on sustainability and humanization.

INTRODUCTION

Currently in Brazil, the health care facilities (EAS) are undergoing a development process mainly in technology and physical structure of the buildings. This process aims for the environmental rehabilitation of their buildings with the application of concepts of space humanization, environmental comfort and energy efficiecny. The Blood Center of Ceará (HemoCE) building is located at Avenida José Bastos, in the city of Fortaleza in the state Ceara. The HemoCE building is basically composed of four blocks united by a central courtyard with a wing regarding the collection and processing of blood, and another wing related to the Day Hospital (treatment of blood disorders); composing a building area of approximately 8,617m². The building is spread over three floors and a half-buried ground floor. The original design of the building is characterized by elements of brutalist modernism; with the strong presence of concrete and apparent masonry. The building possesses an appropriate concept in relation to the characteristics of the local climate, where the facade orientation, glass area positioning and courtyards were well employed.

INTENT AND OBJECTIVES OF INTEGRATED ENVIRONMENTAL ASSESSMENT (IEA)

Aiming for sustainable environmental rehabilitation of the EAS, the Laboratory for Sustainability Applied to Architecture and Urbanism (LaSUS), with the support of the Brazilian Ministry of Health, has developed a method of Integrated Environmental Assessment (IEA) that seeks sustainable rehabilitation by the humanization of spaces. This study presents design guidelines proposed for the case study of the headquarters of the Institute of Hematology of the State of Ceara - HemoCE. Intentions included the use of accessibility features throughout the building, quality of spatial fluxes, the insertion of greenery in the working areas, energy cost savings for the building, and better envelope performance thus improving space quality with the use of natural lighting and ventilation .

PROCESSES/APPROACH FOR INTEGRATED ENVIRONMENTAL ASSESSMENT

The methods used for conducting the integrated environmental assessment involved Post-Occupancy Evaluation (POE), Energy Rating of the building based on Retrofit, the assessment of energy efficiency of the envelope based on the Brazilian labeling system label PROCEL/INMETRO for commercial buildings, and computer simulations in ENVI-met, EnergyPlus and Autodesk Ecotect Analisys 2011 softwares.

Post-Occupancy Evaluation

The process of Post-Occupancy Evaluation (POE), is the analysis of the physical/environmental performance and user satisfaction of the building through on-site survey, interviews with users, data tabulation and arrays of indicators. The methods and techniques of POE, diagnose positive and negative factors in the course of use, from the analysis of socioeconomic, infrastructure, user satisfaction, building systems, functionality, energy consumption and environmental comfort, and finally, the relationship between costs and benefits of buildings [1].

For the POE standard environment typologies of the building were selected where the researchers collected data on the levels of satisfaction and comfort conditions of users, applying specific questionnaires and performing *in situ* measurements of the variables of temperature, humidity, natural ventilation, natural lighting levels and artificial noise in the workplace. Measurement procedures were applied according to the present Brazilian norms on the subject [2, 3 and 4] and used the following equipment: thermo-hygrometers; lux meters; sound level meters; and anemometers.

In the IEA the method of the POE was complemented with the use of computational tools for environmental assessment of external and internal aspects regarding temperature, humidity, lighting and ventilation. Thus, ENVI-met, EnergyPlus and EcotectAnalisys 2011 programs were used. For analysis concerning the urban scale of the building under study, the computational model was developed in ENVI-met program representing environmental conditions (characteristics of the climate of the city), soil surface composition; and characteristics of the built volumes present in the fraction of the immediate surroundings; aimed to simulate aspects of air temperature, wind speed, relative humidity, CO_2 concentration, and the Sky View Factor - SVF. With EcotectAnalysis a virtual building model was developed to determine the levels of direct solar radiation of facades, design of shading devices (checking the efficiency of the proposed elements), and verification of the potential use of natural lighting in certain environments (Day Light Autonomy – DA).

The simulation results of solar radiation incidence on building facades indicate high levels of heat load which directly influence the comfort of building users. Figure 1 illustrates how we analyzed the incidence of solar radiation on the ground level plane and on the facades, with the worst northwest facade. Therefore the simulations guided the proposition for sun protection elements (louvers).

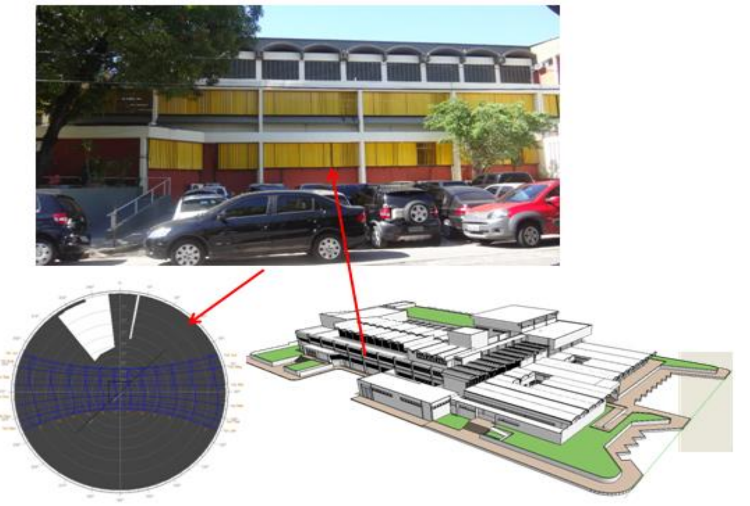

Figure 1 Assessment of incident solar radiation on the northwest facade.

Energy Diagnosis (Retrofit)

With regards to lighting, it was recommended to continue conducting Energy Diagnosis-Retrofit involving a diverse set of activities that vary according to the purpose and the type of occupancy of the facility. In the case of the facility in study, retrofit can be divided into the following steps: preliminary visit and inspection; architectural surveys such as the electrical which include installations and equipment; measurement of electrical quantities; and study of technical and economic feasibility. Measurements of electrical quantities of interest were performed using power equipment analyzers with mass memory, installed at important points of the electrical system, more specifically in the transformer primary booths, tables of distribution and consumption of large electric equipment.

With the information provided by energy analyzers it's possible to determine irregularities in the operation of systems and equipment, through the detection of low power factor, high harmonic distortion and imbalance between phases. Based on measurements and survey data during technical visits, a virtual model of the building from the Blood Center was developed where it was possible to insert envelope data and end uses of the two blocks of the Blood Center. From the developed model stategies were simulated aimed in reducing energy consumption and established three types of intervention: 01 - Changes in air temperature control systems of 24 ° C to 25 ° C; 02 - retrofit of air conditioning systems for equipment with Procel A and 03 - retrofit of the refrigeration system with an average increase of the equipment efficiency of 10%. It was also suggested the gradual replacement of the current fluorescent system (40W) for systems that use 32 and 28W lamps. There was the need to segment the circuit into smaller groups of luminaires, particularly in large environments, as well as segmenting the electrical system of the lights near the windows allowing these to be off when the illuminance levels are acceptable.

As for the air conditioning systems, it was recommended that when new purchases are made, that the energy efficiency label be considered and only level A equipment be acquired. Regarding refrigeration systems, it was observed the demand fluctuation throughout the day due to the frequent removal and storage of materials used in the Blood Bank and requiring strict maintenance of its temperature for the conservation of its properties. It is also recommended the gradual retrofit of condensing units.

For aspects of eletric energy quality, it is recommended to pay attention to the current imbalances in the electrical panels, always trying to keep balanced phase currents (better load distribution). The use of electronic equipment with power factor within the standard limits (> 0.92) is also recommended.

Energy Efficiency Assessment (National Certification of Energy Efficiency)

The Brazilian certification for energy efficiency in buildings is based on the Technical Regulation on Energy Level Quality of Efficiency for Commercial Buildings, and Public Service (RTQ-C) [5]. In RTQ-C, the building is evaluated in three items, with different weights in the overall standings of the building: envelope (30%), lighting system (30%) and air conditioning system (40%) system. From the analysis of these instances the building can receive the National Energy Conservation Label.

For this case study we used the prescriptive method of RTQ-C to evaluate the envelope of the building, consisting of the roof, facades, and openings; floor area and volume; façade orientation; checking of the thermal properties of materials and construction systems of facades and roofs, defined in the project specifications or site visits. The prescriptive method calculates the consumption indicator of envelopment (CI), which is a dimensionless parameter for benchmarking the energy efficiency of the envelope. The consumption indicator establishes the behavior of the envelope on the energy consumption of the building

From the collection of data and calculating intervals of energy efficiency in the building, in its current state the efficiency level of the envelope is B. This is mainly due to aspects of absorptance and transmittance of the building materials. Given the absorptance of the surface materials, it was observed that the facade with dark colors, would not meet the limit values for label A. Thus, it was recommended the rehabilitation of the exterior walls with light colors and use of materials with low transmittance, as required by the RTQ-C for Bioclimatic Zone 8.

INTEGRATED ENVIRONMENTAL ASSESSMENT DIAGNOSIS

The Integrated Environmental Assessment resulted in a diagnosis of the reviewed elements. From this diagnosis it was possible to extract guidelines upon the assessment of functional and humanizing aspects evaluated *in situ*. Based on these guidelines, an intervention for the sustainable rehabilitation of Hemoce was proposed. The diagnosis obtained for aspects evaluated (Post-Occupancy Evaluation, Energy Diagnosis - Retrofit, and Energy Efficiency Label Level for the envelope), has established intervention points both in the main and anex buildings

Building of the Blood Center of Ceara (HemoCE)

Based on the guidelines outlined, the proposals for the ground floor were towards spatial organization according to their functions; humanization and integration of spaces with green areas and courtyard; and other operational issues such as the reactivation of service lifts and creating specific areas such as childcare; rest areas for patients/visitors/employees; sanitization area of containers; relocation of environments for better fluxes.

These interventions were based on surveys carried out *in situ*, and especially with the help of staff from each sector. Another important point was the intention in maintaining areas considered irreplaceable as toilets and the central of computer systems (Figure 2).

The guidelines proposed for the first floor aim to solve the major problems identified in surveys. First it was sought to improve the flux of donors and employees of the building keeping in view the requirements of the Ministry of Health. It was suggested a much needed accessibility improvement for donors (currently done only by stairs) by creating ramps for people with special needs (PSN); and creating bathrooms for PSN in the waiting area of the donor; plus a separate output for donors; improvement and expansion of the area of service; creation of receiving results from the examination room; among others. Moreover, in the donation area, sectors for processing blood were thought; better distribution and segmentation of spaces associated with the Hemoce board; and search of humanization and integration with green spaces, revitalizing the inner courtyard (Figure 2).

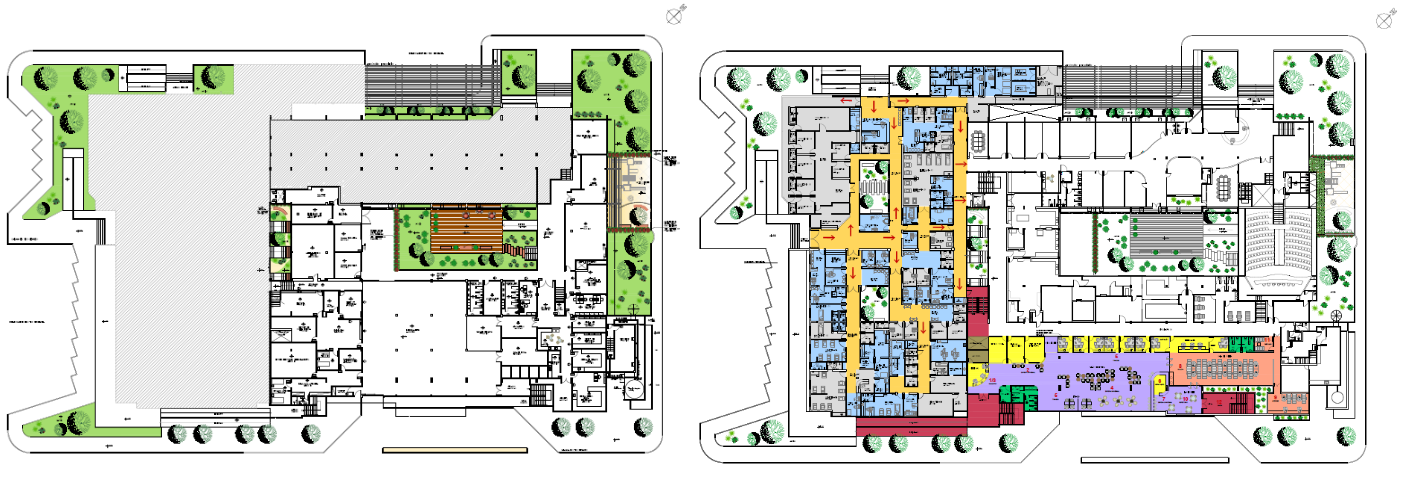

Figure 2 (a) Floor plan of ground level and (b) and floor plan of the first level of HemoCE blood center.

Interventions on the second floor were given towards the organization and segmentation of activities, concentrating the laboratory and administrative activities. As this floor has undergone a recent renovation in a considerable area, interventions sought maximum improvement with minimal demolition. Another important point was the integration of environment with green areas and gardens; also enabling the use of natural light and ventilation (Figure 3). The third floor focused on the reuse of underutilized spaces, such as deposit areas. There was also the inclusion of the financial administrative sector, living area and gymnastics, restaurant for employees; and areas for garden and green roof (Figure 3).

Figure 3 (a) Floor plan of the second level and (b) floor plan of the third level of HemoCE blood center.

For the top of the building green roofs were created to contribute for the reduction of outdoor air temperature and heat load transmission to the environment. In some sections these green roofs became gardens with access by employees. These gardens contribute to the humanization concept proposed in this paper, in addition to promoting harmony and wellbeing. Simple modular elements are proposed for the composition of green cover. Such elements are now easily found in the market and have easy implementation and maintenance.

Annex Building

For the annex building proposed the same concepts of HemoCE main building were looked; humanization, sustainabilities, and use of local climatic aspects. The internal spaces were intended to house some activities removed from the existing building; areas such as housing; training rooms; library, etc.. Moreover, the new block houses a museum of HemoCE and areas that can be used for meetings and multipurposes (Figure 4).

Figure 4 (a) Floor plan of ground level, (b) Floor plan of the first level, (c) floor plan of the second level, and (d) annex building facade.

INFERENCES AND CONCLUSION

The policy of humanization of public health units, coupled with the need to reduce the action of infectious agents in health care facilities, and the impact these environments imposes its users and the environment, are requesting more and more efficient facilities. An efficient building is one that is thought out and executed under bioclimatic strategies such as the use of passive environmental conditioning systems, renewable energy and building materials which are suitable to the climate in question, performs its functions maximizing the safety and comfort of its users, and finally saving energy and reducing the impact on the environment.

In order to ensure the vitality of the future use of the building, the program was organized to be flexible meeting the basic needs and transcends it to incorporate elements of humanization in the form of fresh, colorful and friendly open spaces, not leaving aside its functionality and meeting norms and regulations. The building's current transparency remained, sun protection devices have been improved to allow daylight access and the perception of diurnal changes of light, so it offers a continuous outdoor relation. Bright city light is filtered, softened and introduced from the inner courtyards that continue to contribute to create a pleasant working atmosphere.

The management floor which houses the executive offices and protocol, as well as the legal spaces, opens to an interior garden, where the presence of greenery is present to restore the balance of the current environment and the building functions.

Climatological criteria guide the construction of green roofs to mitigate the strong incident heat load, but humanization criteria also contribute for environmental comfort of the health facilities. Greenery appears in the quotidienne visuals and also in spaces designed for leisure and amenities.

To achieve high level quality, the Ministry of Health is advising the National Public Blood Centers to seek certification of their services as a way to ensure quality. Herein lies the challenge: to advance the issues of quality management, allowing the pursuit of service excellence and ensuring blood safety to public health users. Therefore, the General Coordination of Blood and Blood Products of the Ministry of Health, has developed the National Qualification Program of Blood Centers. The development of this work aims at the continuous improvement of services, as well as the ability to collaborate effectively with the process of external accreditation. The scope of this study shows the actions to be developed with the National Public Blood Centers with the aim of expanding and improving not only blood services but also the buildings which provide these services, ensuring safety and environmental comfort in all levels to public health users.

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‘The Open Air Office’
Climatic adaptation of the office building typology in the Mediterranean

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ASTRACT

The paper reports on a dissertation project undertaken at the Architectural Association School of architecture towards a Master’s degree in Sustainable Environmental Design by the Author. The starting point for the research was the troubling common practice of office buildings in Israel - racing towards the tallest, highly mechanical and fully glazed buildings, scarcely applying any environmental considerations and occasionally using the local green point system code to render them as ‘green’. This research aims at contextualizing the office building typology to the local Mediterranean climatic conditions of Israel; based on a theoretical framework and a detailed study of local common practices and climate, followed by an analytic optimization study, the ‘Open Air Office’ concept is introduced: one which uses an integrated environmental design approach to rethink some of the core values that drive office building designs in Israel today.

INTRODUCATION

Adoption without adaptation

In contrast to a history of successful adaptations of international building styles in Israel which demonstrated high sensitivity towards the local climate, the adoption of the fully glazed office building typology in Israel- mostly throughout the late 80's and 90's- has been almost automatic (Figure 1), with very little awareness towards the environmental impacts of these buildings on all levels - from the cityscape to the occupant.

(1)

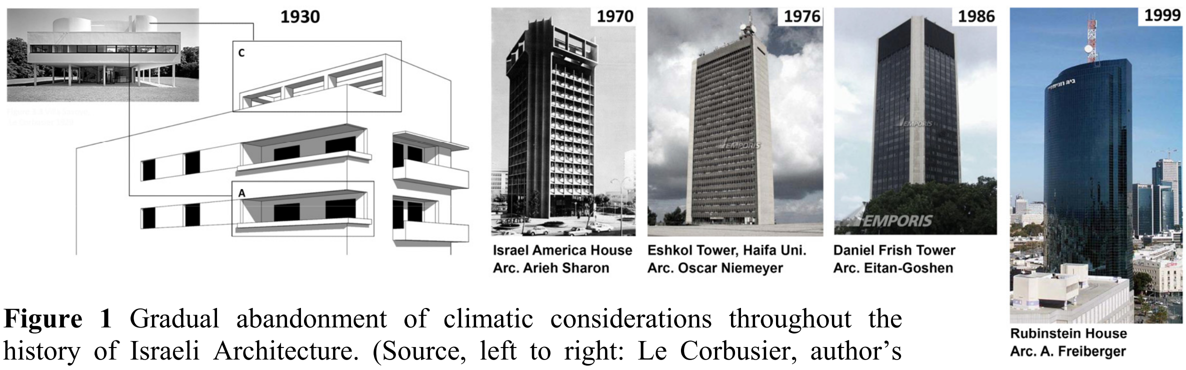

Figure 1 Gradual abandonment of climatic considerations throughout the history of Israeli Architecture. (Source, left to right: Le Corbusier, author’s sketch, Arieh Sharon, Emporis, and Telavivinf.com)

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Starting from evaluating the performance challenges of this common practice in Israel against the potentials of the local climate, this research began by questioning how to improve performance by taking simple considerations into account in the early stages of office buildings design in Israel; using the common practice as a base case this study gradually explored the possibilities of optimizing both comfort and efficiency by applying preliminary, good and further on best practice environmental strategies that fit Israel's climatic conditions. In conclusion, this research aimed at offering a platform for architectural design that will give a new angle to the correlation between the contemporary indoor office space and the local climate.

Methodology

Firstly, a study was conducted on new global workplace trends and explored the potential of new occupancy patterns to affect both comfort and performance levels of office buildings in the near future. Secondly, the local climate of Israel was studied, followed by relevant basic and advanced environmental strategies evaluation. In order to study the existing context, combined literature and analytic work were used to help gather insights regarding the current performance, layout and materiality of the local common practice office building. These insights helped highlight specific challenges and potentials, so as to define the base cases towards further studies. The analytic work, which was focused on thermal, daylight and Solar geometry aspects, moved through different levels - from the simplest preliminary environmental concepts to more advanced ones, evaluating their potential to improve both efficiency and comfort levels within the typical office space; Simulations were conducted by using Tas (thermal, by EDSL), Ambiens (CFD, by EDSL), Radiance (Daylight, by Berkley lab) and Ecotect (solar geometry, by Autodesk) software. The last part of this research explored and analyzed the unique opportunity of the Mediterranean climate to open up the building's envelope towards the outdoors throughout different seasons of the year with correlation to the changing internal office layouts. The performance analysis for this 'Open Air' concept, was followed by an applicability study of one possible office building configuration, which proved its potential to work very well with the local climate and office culture while providing high performance and comfort levels within the office space.

THE FUTURE WORKSPACE

Nowadays, in contrast to the prescribed tasks of the traditional "office factory" through single fixed workstations, the economic shift towards the "knowledge" society has created a need for variety of alternative spaces, with higher levels of interaction and autonomy (Harrison et al. 2004); As new technologies enable people to work virtually anywhere and new interaction between users within the office space through virtual computing (Johnson et al. 2011), a new office layout terminology has been evolved which encourage higher levels of flexibility, collaboration and autonomy (Duffy, 1997);

The Israeli work culture, characterized by a vivid, creative informal atmosphere, with strong communal routs is highly exposed to global trends, which are commonly taken into account during the design process. Therefore, the future trends which shape workspaces globally served as an important anchor for this research.

ISRAEL'S OFFICE BUILDING DESIGN CULTURE

Common practice design

The research has focused on the climatic and urban context of the Tel Aviv metropolitan area, the economical center of Israel, due to its large conglomeration of office buildings.

Building design. High rise office buildings are becoming common within the Central Business District of Tel Aviv. The Israeli market is highly speculative, predominated by "Shell & Core" buildings, being designed within a central core rectangular layout due to costs and internal space considerations.

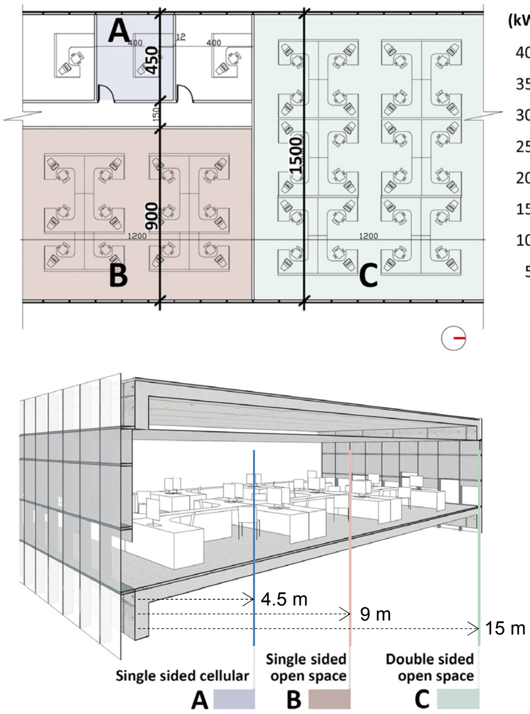
Materiality. Reinforced concrete frame & floor slabs is the prevailing framing method, cladding is usually done with different variations of curtain wall systems which combine glazing and opaque cladding materials; Fully glazed buildings are very common and solar control is usually applied by reflective or tinted glazing systems combined with internal venetian or roller blinds.

Office space layouts. The demand for enclosed private offices is still relatively high; the common practice consists of 4.5 deep office spaces with changing widths. Double-sided or single-sided open space offices are becoming more and more common, with depths ranging from 9m (single-sided) to as much as 30m (double sided); These observations helped generate the base case as shown in Figure 2.

Performance criteria and benchmarks

Although it is widely acknowledged (McKinsey and Co. 2009) that most buildings in Israel are big energy consumers, official energy consumption database or performance criteria for office buildings are currently unavailable. In order to establish a reliable reference point for the performance studies throughout the research, data was gathered from HVAC experts in Israel and was correlated with published cooling energy consumption data from similar climatic zones within the US. For this comparison, Tel Aviv climate had been considered as part of the A2 category (using ASHRAE international climatic zone definition) and energy consumption data of office buildings in Houston Texas was selected as a general reference.

(2)



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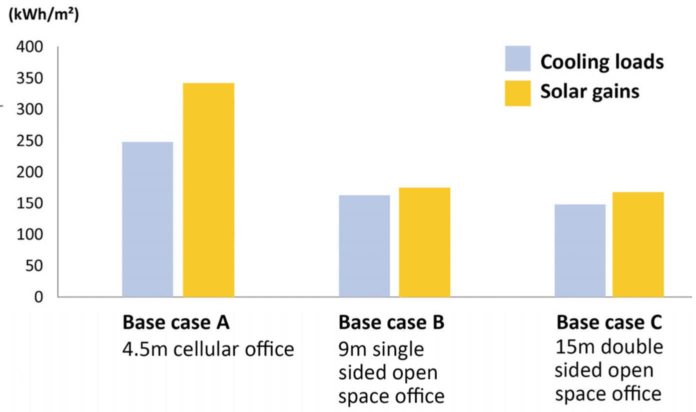


Figure 2 Common practice office space base case.

Figure 3 Common practice energy cooling demand for 3 typical office layouts[1] (in kWh\m2, Source: TAS).

Common practice performance

Based on findings from the common practice design studies, three layout configurations have been modeled, as shown in Figure 2. The boundary conditions[1] for all the three base cases have been closely considered in regard to typical glazing, solar control, occupancy and materiality properties which have been identified as prevailing during the common practice studies.

As a starting point, in order to establish a reference for further parametric optimization studies, a thermal simulation was conducted using TAS for the three different base cases facing West (or East West) orientation (a very common orientation for office buildings with proximity to the Israeli coastline). The combination of high exposure, together with their West-facing orientation, resulted in very high cooling energy demands across all three office layouts, mostly in cellular office layouts due to

[1]Boundary condition in all cases included fully glazed 75% WWR designs, oriented West (or West-East orientation in double sided configuration), no external shading, w. internal semi opaque blinds.

their high window to floor ratio (Figure 3). These results were found to correlate well with the data gathered from the actual practice in Israel, in which HVAC systems are being designed to supply cooling energy of approximately 200 kWh/m^2 annually.

ANALYTIC WORK - OPTIMIZATION PROCESS

Preliminary optimization

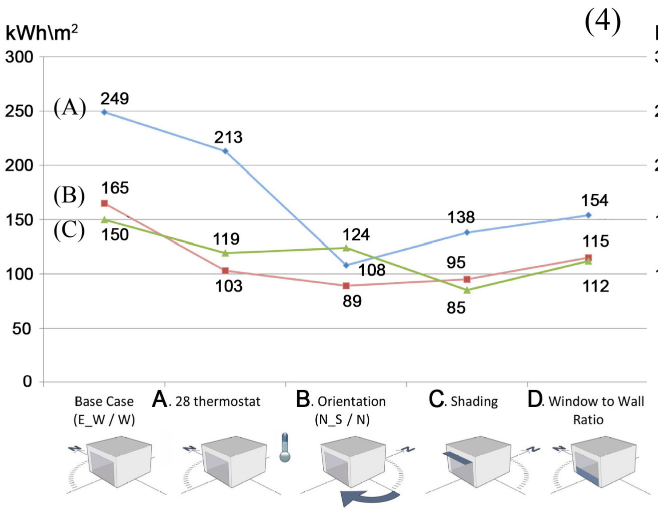
The first level of optimization was set up to explore the hypothesis that a high level of efficiency and comfort could be gained by applying very basic environmental design strategies at the very early design stages of office buildings. The parametric approach included four different strategies which were assessed separately (Figure 4), and were conclusively merged into different typical combinations according to the common office building design scenarios in Israel (Figure 5).

Set point temperature. When considering the adaptive comfort model, the common fixation of the temperature set point on 23^{o}C or even lower during cooling period seems inappropriate. In order to test the implication of set point changes on performance, the three base case models were thermally simulated for three different set point temperatures (23, 25, 28^{o}C); Simulations showed how this simple operational change could substantially improve the annual cooling loads in all office layouts by 20-30%.

Orientation. Thermal simulations for the three different layouts revealed large amplitudes in annual cooling energy demand between different orientations. In contrast to the Cellular base case which is more thermally fragile, open space layouts reacted more mildly, with the double sided model showing very limited performance effect by orientation.

Shading. Different external shading geometries were simulated and studied in Ecotect for all four major orientations. After daylight levels had been verified through simulations (Radiance), selected optimized shading configuration were modeled thermally TAS.

Window to wall ratio (WWR). This study explored the balance between minimizing exposure for thermal considerations while insuring adequate daylight levels for the 3 base case layouts through different orientations.



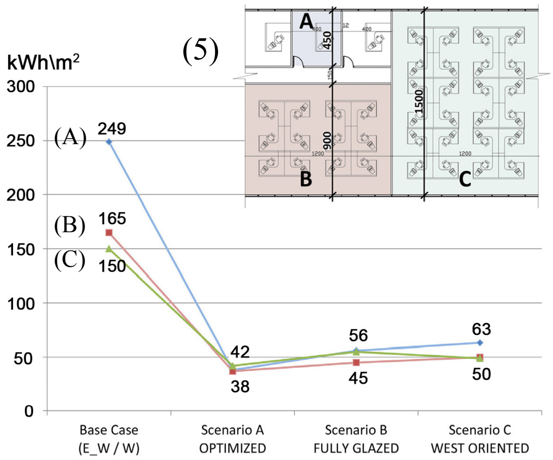


Figure 4 Parametric optimization study of annual cooling energy demand for 3 typical office layouts (in kWh\m^2, Source: TAS).

Figure 5 Annual cooling energy demand for different preliminary optimization scenarios (in kWh\m2, Source: TAS).

Scenario A - Optimized configuration (A+B+C+D).

Scenario B - Fully glazed configuration, all parameters applied besides the reduction in WWR (A+B+C).

Scenario C - Sea View/Western configuration, all parameters applied besides optimized orientation (A+C+D).

Preliminary optimization. Figure 4 shows the effect of each of the parameters on the base case cooling energy demand; the chart demonstrates how orientation is critical for cellular offices (A); when oriented North, cellular offices will perform better than the double sided open space (C) due to reduction of solar gains being replaced by the effect of other internal gains. The chart also shows the changing trends between single (B) and double sided (C) open spaces, the latter being less effected by orientation due to its double orientation exposure. The combination of different strategies (Figure 5) indicates similar trends in cooling energy demands between the three layouts, in which differences observed between the three base cases dissolved in different scenarios when solar gains were being effectively modulated by applying external shading.

Good practice optimization

Aiming at higher performance and comfort levels, the following studies evaluated the potential of more advanced strategies to further reduce the resultant temperature and cooling loads accordingly;

Glazing properties. The thermal balance of glazing, being a dominant component, was studied; for each base case, five envelope properties were considered, each offering a different balance between heat gains vs. losses as well as different daylight intensity (Figure 6).

Thermal mass and night ventilation. The possibility of applying high thermal capacity materials within the common office space layout was narrowed down to the 3 scenarios;
(a) Exposed concrete floor, (b) a + concrete partitions, (c) b + exposed ceiling. Thermal simulations for the three scenarios revealed considerably lower days within comfort for scenario (c) during cold periods, indicating that heating might have to be introduced, and that the 'cold' outcome might work better in cases of high internal gains due to occupancy patterns or equipment usage.

Natural ventilation. These studies evaluated the balance between space cooling and physiological cooling considerations; after determining the required air flow rates needed to optimize performance, CFD simulations had been used in order to evaluate resultant temperatures and air flow rates throughout the office space for a typical mid-season week. Natural ventilation studies proved that in periods when external temperature reaches above certain limits, the space cooling effect achieved by natural ventilation was often very limited; however, under the same conditions, physiological cooling effect by air movement throughout the space could effectively lower the resultant temperature towards comfort.

(6)

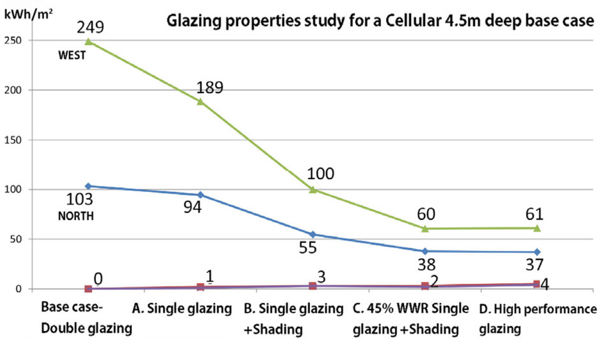


Figure 6 Annual cooling energy demand of five different glazing properties scenarios for Cellular base case (in kWh\m2, Source: TAS).

(7)

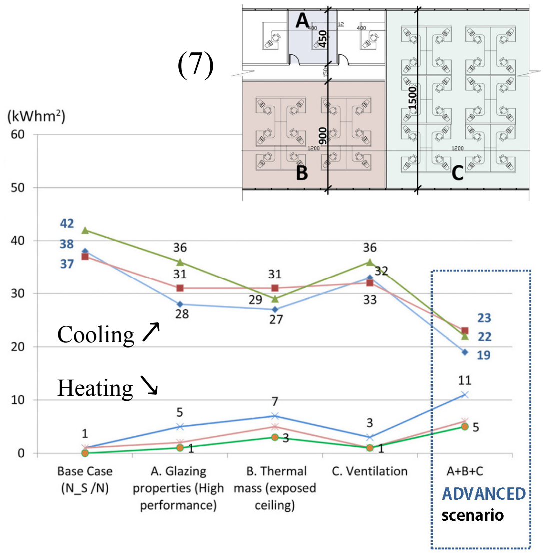


Figure 7 Cooling energy demand for different good practice optimization parameters (in kWh\m2, Source: TAS).

Good practice optimization. The study showed how further efficiency improvements could be achieved by applying advanced strategies (Figure 7); however, high internal gains will still generate an inevitable need for cooling (mostly during hot period), and by cutting off solar gains during cold period, heating demand will increase. Nevertheless, during the process of their evaluation, strategies such as natural ventilation or thermal mass should also be measured against their added values for the quality of the space; i.e. by creating desirable air flow and stabilizing internal temperatures.

Towards best practice

Aiming towards the 'zero carbon' office space, this part of the research, within the recognition of air conditioning as the main energy consumer, focused on the passive cooling solutions that might reduce or eliminate its use. After four selected passive cooling strategies had been evaluated (based on data from contemporary research, literature and precedents), this section highlighted radiant and ground cooling as the most effective passive cooling strategies for Israel's climate. However, considering the highly speculative Israeli market, the applicability of these strategies in Israel is expected to face strong market barriers, and most probably would be considered only for a 'use value building' (Harrison et al. 2004), custom designed for specific end user organization. The limiting potential of the Israeli air to effectively absorb excess heat indicates the need for hybrid or mixed mode systems in which low energy mechanical systems are coupled with natural forces; e.g. hybrid evaporation systems could be very efficient, as well as heat recovery mechanisms which could be coupled with the ground cooling system. These should be integrated aside renewable systems (which were not addressed in this research), mostly solar systems, in the light of Israel's high solar radiation availability.

THE OPEN AIR OFFICE CONCEPT

The inspiration for an 'open' approach for office buildings in Israel was drawn from the local building tradition; one in which the potential of outdoor and semi-outdoor activities to take place throughout a considerable time of the year had been widely recognized, mostly throughout the pre- AC era. The 'Open Air' concept aimed at reintroducing that potential to the contemporary office building typology (Figure 8). The need for diversity and informal reflection and meeting areas as part of the new office space, generated an excellent opportunity to reinvent these spaces in the Israeli office building typology through transitional or outdoor spaces. A dynamic semi-outdoor space, which could be opened or closed according to the user demand and the outdoor conditions, could serve as an extension to the internal office space and activity.

Analysis methodology

For the thermal and daylight analysis, a double sided section had been chosen with similar proportions as the previous 15m base case used throughout this research. The layout of 15m X 12m which included the fully optimized configuration (as previously studied) was coupled with a 3m transitional space projected towards to South, with openable full height glass partitions between them calculated to be opened when the adjacent semi outdoor space temperature was within the boundaries of comfort (Figure 9).

(8)

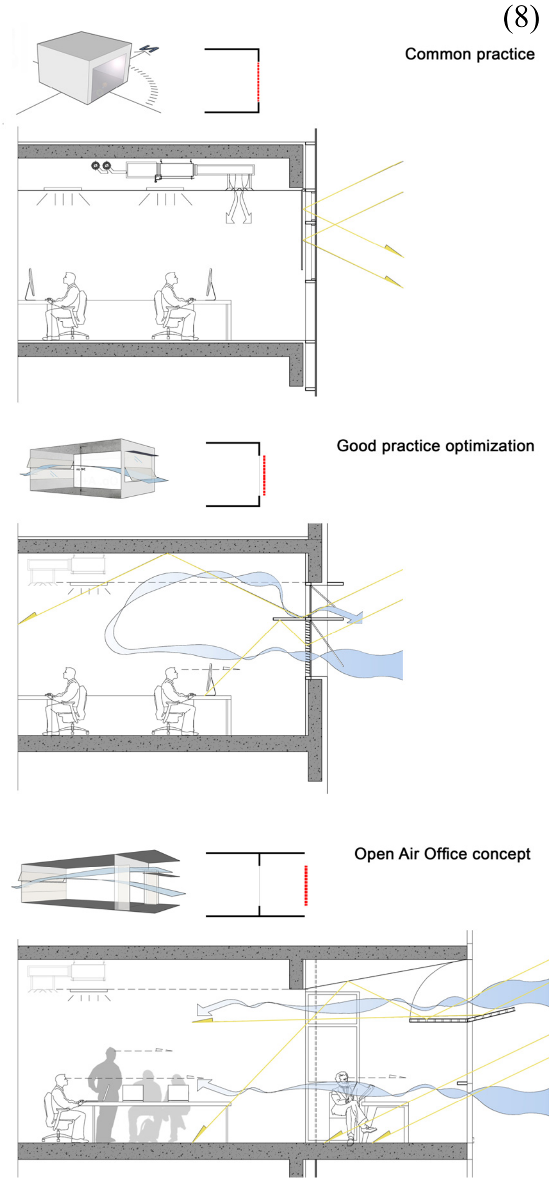
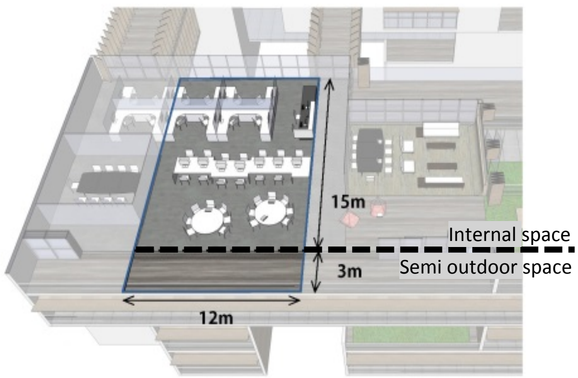


Figure 8 the Open Air Concept evolution

Thermal simulations for the internal office space in a free running mode (Figure 10), revealed resultant temperature fluctuating very closely to the external ones and relatively high levels of comfort hours yearly; strong potential was evident for opening the office space to the outdoors in sunny days during cold-periods, as well as through most of the mid-period. Daylight simulations for the same boundary conditions showed the potential of the adjacent space to serve as an effective buffer from direct sunlight without compromising the required daylight levels in the office space.

(9)



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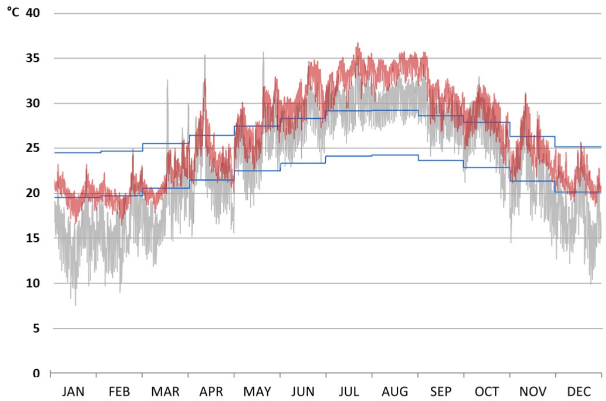


External temperature (°C)
Internal office space resultant temperature (°C)
ASHREA 55 comfort band

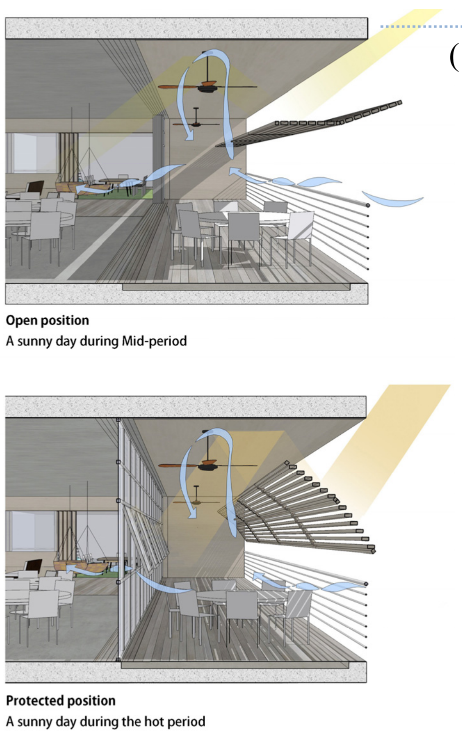
Figure 9 Case study model for the Open Air Concept analysis.

Figure 10 Annual resultant temperature simulation (Source: TAS).

Thermal vs. visual comfort

By applying adaptive opportunities and space diversity, the occupants interact both with building elements and with the building space. In addition to the basic environmental strategies applied (orientation, exposure, ventilation etc.), the application of the adjacent semi-outdoor space towards the South is taking performance further - by serving as a mediator between internal and external conditions, and by offering a good balance between thermal and visual issues. Figure 11 shows how the deep projection addresses glare and excess heat issues effectively while the adjustable louver-shelf serves as solar protection for the semi-outdoor space and redistributes light towards the depth of the office space.

(11)



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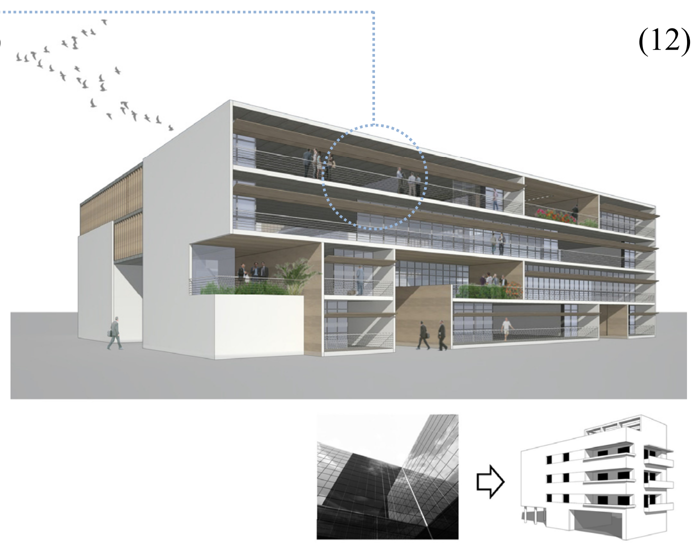

Figure 11 Adaptable envelope design.

Figure 12 Exterior view of the open air case study showing the design expression of the environmental concepts.

Activities

The diversity of space which is required to address new patterns of office activities have been addressed and distributed according to visual and thermal considerations; e.g. presentation areas in less exposed spaces, informal areas in semi outdoor spaces with higher tolerance levels to the outdoor climatic conditions and fixed workstations, with higher control levels and stabilized thermal conditions.

Design expression

The external figure of the building (Figure 12), reflects the shift of mind from the sealed glass building, disconnected from its environment, to a new model in which different levels of exposure drive the building's external image. The correlation between the external layout and the performance becomes complete and corresponds with the local architectural design language from earlier times in Israel's history, in which climatic considerations helped contextualize the modern trends to the local climate.

CONCLUSION

This research showed that by adopting an environmentally responsive approach, the troubling performance of the Israeli common practice office could be dramatically enhanced - even up to a 'zero energy' balance. As overheating was identified as the main issue, optimization phases mostly focused on blocking solar heat gains while dissipating internal ones; while preliminary optimization studies showed how effective simple design decisions could be, In further optimization levels, when direct solar gains were effectively blocked, internal heat gains became predominant, and issues such as control, adaptability and thermal vs. visual comfort balance became critical to comfort and performance.

Aside the more 'technical' aspects which evaluate comfort and performance through numerical prediction, the architectural performance of the space must also be accounted for and correspond to the office concepts of tomorrow. In the new work environment where borders dissolve (e.g. 'home' and 'work' or 'virtual' and 'real'), the same levels of flexibility and adaptability will have to be applied to the spatial differentiation between 'in' and 'out'; The ability of the coastal Mediterranean climate to dissolve these boundaries within comfortable outdoor climatic conditions, offers the unique opportunity to open up the sealed office 'glass box' to the outdoors. The open air office approach had been incorporated into this concept, in which new office organizational trends and spatial design values reintroduce the potential for working with the Israeli outdoor climate.

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Buildings without electricity in early development of Mumbai City- A case study on Asiatic library building the town hall of Mumbai.

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ABSTRACT

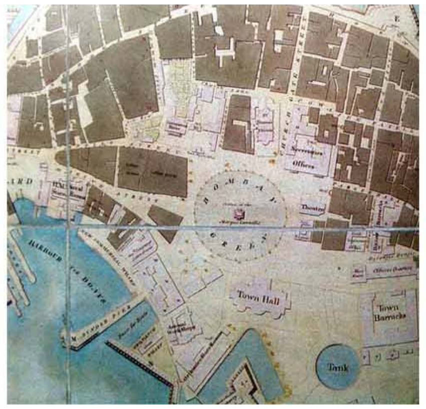
The city of Mumbai was developed by British in early 18th and 19th Century predominantly as an industrial town. Mumbai was introduced with electricity only in the 20th century and the buildings prior to this were designed without any deliberation of electrically driven active systems.

The paper highlights the induction of high technological understanding of the time and its appropriate application adhering to the climatic conditions of Mumbai. To further understand and analyze these understandings of the designers, a case is identified and evaluated. The Town hall or the Asiatic Library building in Mumbai designed and built in 1829 is selected to be assessed for the passive design strategies.

The paper uses qualitative method of analysis to understand the right and as designed programs then the existing overlapped functions. With change in the use of the building it is evident that the original program is modified. The authors with appropriate literature references and on site observations build the case for the as designed functions of the building which coincides with climate responsive techniques. The paper further uses the quantitative method of analysis to find if the strategies respond to the user comfort of the building. The building was analyzed for following aspects of design namely- Site setting and orientation of the structure, Daylighting and identifying the factors responsible for thermal comfort. The observations from the analysis indicate a strict inclination towards climate responsive design for the building and utmost priority to the user comfort. The study concludes with the fact that the building was designed to function without any electrically driven systems with importance to factors like Daylighting and Natural Ventilation, making it "off grid" in all aspects.

INTRODUCTION

Mumbai earlier known as Bombay is metropolis built in the early 18th and 19th century by colonial rulers. First the Portuguese and the British administered the island city and streamlined its development. The Bombay town was established primarily as a navy garrison of armed forces by the Portuguese and was surrounded by fortified walls. The shift of powers to the English administrators facilitated the need of a harbor town which could be a potential commercial hub for business and trade. Following the development trend, the British rule in early 1800's established the need for a social platform as integral part of the upcoming town. A public social forum building in form of a Town Hall, which could also house a library, was perceived. "The Asiatic Society of Mumbai was founded by Sir James Mackintosh, a distinguished lawyer, jurist and public figure in England who became the Recorder or the King's Judge for Bombay. Known then as the Literary Society of Bombay, it met for the first time on November 26, 1804."The Asiatic Society was proposed to be integral part of this building. Public and private funding led to completion of this building in 1829. The building was designed by Colonel Thomas Cowper and was completed by many prominent Architects and Engineers of Bombay Engineers including Charles Waddington.



INTENT AND OBJECTIVES OF APPLIED RESEARCH/BUILT WORK

The Building was an important epicenter of commercial, social and administrative workings and The Town Hall was a catalyst in building the reputation of a new town. This important building seen as a landmark in the up come of a town was built in a scenario where electricity was not introduced. With this in context it becomes important to study such building for its methods of design and passive design considerations. Objective of the research is to discusses the ideology of design with respect to 'off grid' buildings at the prevalent time. The research intends to underline the issues of passive architectural design which include daylighting and natural ventilation introduced as a design consideration rather than added features.

PROCESSES/APPROACH

The analysis was carried to understand the right and as designed programs then the existing overlapped functions. The study was aimed at investigating concepts of passive designs which are prevalent in the town hall, along with correlation of its spaces which have been designed in a manner which makes the building function without the eclectically driven cooling systems. The concepts can be credited to the non availability of electricity when the building was designed and built.

In order to achieve a comprehensive approach the analysis was carried out on two levels, namely qualitative analysis and quantitative analysis.

The qualitative analysis evaluates the building on following parameters,

- Site context
- The layout of the original building in response to the passive technologies in absence of electricity**.**
- Overlapped programmers at later stage and user interface**.**

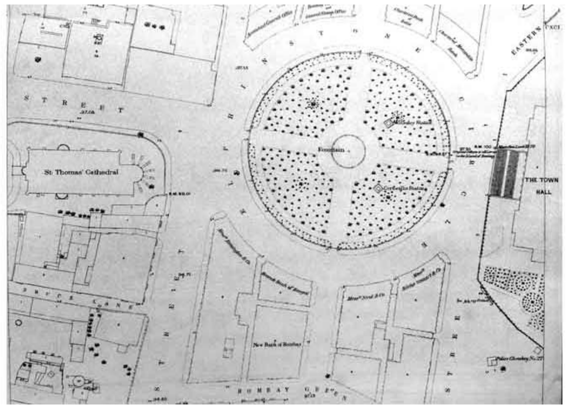
SITE CONTEXT

Climate

Mumbai is located on the west coast of Indian Peninsula with the climate type categorized under warm and humid (Mujumdar M., 1997). The strong South Westerly wind dominates the island city and subtle wind is encountered from North and North East. The climate can be distinctively bifurcated into three seasons namely the Summers, Winters and Monsoon. The summers are warm with high humidity due to close proximity of sea. Monsoons are featured with territorial rains with average rainfall up to 2500mm, while the winters are present with temperatures falling not beyond 12 degrees Celsius. The day and night time temperatures are confined in limits and does not fluctuate. Humidity during the monsoon season is high and similar situation is prevalent in the summer months. The summer's record temperature's on higher side of 30 degrees Celsius and sometimes even crossing the 37 degree Celsius.

Site sitting and the Building

Situated in the "Fort" area of the Mumbai city, town hall dominates the central and important precinct area of Horniman Circle, earlier called the Bombay Greens. The area has not only been historically important but also been arguably heart of the City. The Bombay Greens or presently the Horniman circle gardens forms a pivot to spoke commercial buildings on north and south. The west axis is flanked by 17th century Gothic church of St. Thomas Cathedral and East end with the Magnificence of Town Hall located on East side. The town hall is approached from the west coasting the Cathedral of St. Thomas on right and heading the Town Hall through dense vegetated Horniman circle garden. The very location of this building is glorified by raising the platform induced by a grand flight of 30 steps leading the building. The façade is Greek Doric styled and columns dominate the antis. The Location of town hall is dominated by the East West axis. The grand entrance faces the West and is flanked by similar elevations on the north and south facades.



“The huge projecting window canopies with intricate fretwork are for providing shade to the rooms within- an adaption to the tropical heat. The large entrance hall immediately behind the central portico is the Town hall proper, with a row of fluted Corinthian columns that have gliding on the capitals. The strong interplay of light and shade accentuates the neo classical austerity of that area.The Town Hall was the centre of civic activity and debate, and the Asiatic Society was a centre of research on and documentation of knowledge of the Orient.”(Ganesh K., Thakkar U., Chedda G., 2008)

The town hall is oriented in East West axis and is two storied building. The building is rectangular in plan admeasuring 200ft X 100ft. The West façade dominates the building as it is columnated with Doric fluted columns. The masonry walls and a load bearing pitched roof enclose the programs of the building.

THE LAYOUT OF THE ORIGINAL BUILDING IN RESPONSE TO THE PASSIVE TECHNOLOGIES IN ABSENCE OF ELECTRICITY.

The town hall was built to host a convention hall with proposal to allow various functions to be organized. As the layout suggests that the most important part of the building, the grand hall was located at the centre of the plan. This was surrounded by symmetrically arranged library and administration areas on North and South sides. Preliminary the segregation of the original layout can be done where the quite zones were separated from the nosier areas. The hall and the ceremonious areas were at the centre where colonnade of Doric orders glorified the function. The record rooms were placed with the store rooms and council rooms at ground floor area. The important Grand hall with reading areas and the prestigious Asiatic Society is located on the intermediate floor which is connected directly by the grand stairs.

The East and the West façades were protected by a colonnade suggesting gothic architectural influenze on west façade with a non decorative yet a protecting lean to roof. It can be noted that due to absence of electricity a clear intentetion to introduce elements of daylight and natural ventilation are stressed upon. The care has been taken to understand the low sun on the west face and preventive measures in form of second façade to shade the internal wall is implied. The windows are further protected by sun shades or “Jhilmils”. The authors observe that the window shutters are installed with a louver system which not only keeps west, south west wind flow intact but also obstructs the harsh evening solar ingress.

OVERLAPPED PROGRAMS AT LATER STAGE AND USER INTERFACE.

The town hall presently is converted completely in to library. The ceremonious Grand hall accommodates a reading section and temporary offices on the ground floor section. Although the library still is not air conditioned and daylit, artificial light and mechanical wall fans help achieve the comfort. It can be noted that the ground floor occupies government offices which function with complete change in the layout as designed. The use is segregated with the public areas occupying the above floor and the lower floor being occupied by the admistrative and non public functions. The town hall is merely a building without the original function and intent.

OUTCOMES

The site was comparatively open when the building was designed and hence the cross ventilation along the building can be noted to be an important factor in attaining the orientation. The planned layout with the Bombay Greens, Horniman circle at the centre facilitates the wind flow with strengthening the wind currents from West. The climate is Warm and Humid which results in cross ventilation as an effective comfort strategy. In this scenario the East-West building orientation seems apt solution for natural ventilation and cooling. It can be clearly noted that the building responds to the overall function carried inside and is evident from the r. The appropriate sizing of the windows and protective layering of appropriately designed shades enable the internal areas to be adequately lit and naturally ventilated. The louvered windows are designed as to control the opening size of the shutter. The user can achieve desired comfort by controlling the angles of the wooden louvers. Not only the daylight is optimized but also this arrangement avoids solar ingress and allows uninterrupted wind flow.

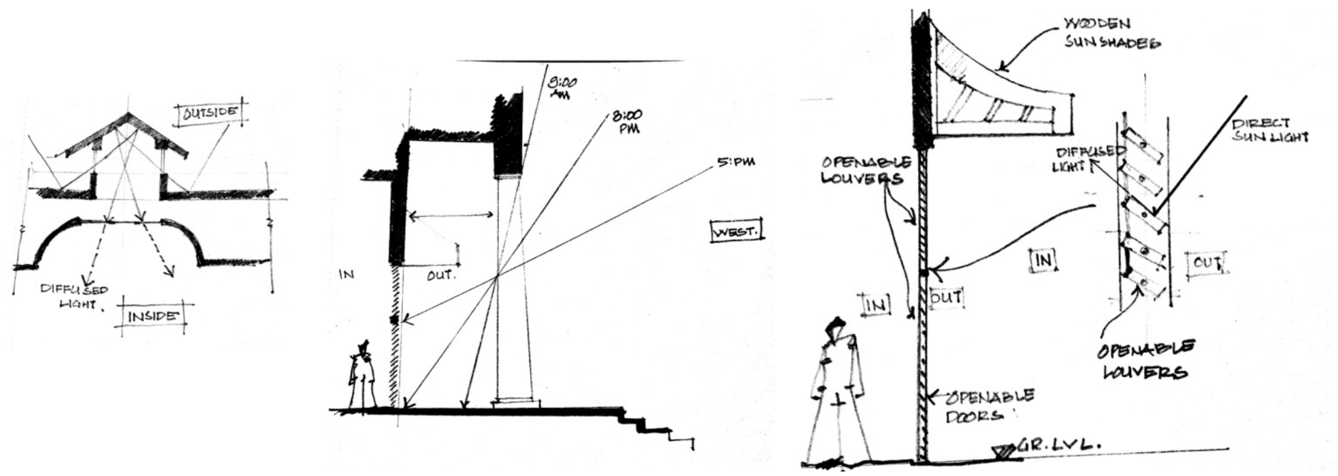


Figure 1 (a) The Lantern light located at the Central Grand Hall (Authors). (b) Sun angles at the west façade (c) Section showing the weather shade (Jhilmils) and louvers (Authors).

QUANTITATIVE ANALYSIS

Daylighting

The Quantitative analysis was carried out to explore the light inside the spaces of the building. The identification of Town halls lighting techniques used was carried out with the help of identification of strategies used in the building which were apart from any electrical source. The method is where the source of day light is separated with onsite identification of the techniques. A detailed understanding of the type of lights is carried in order to understand the implications of each source of light.

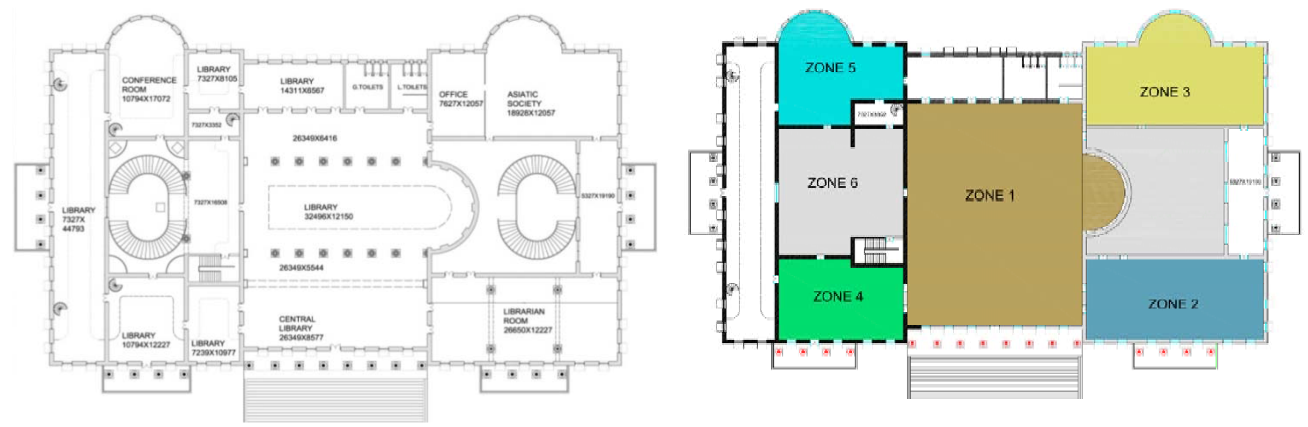
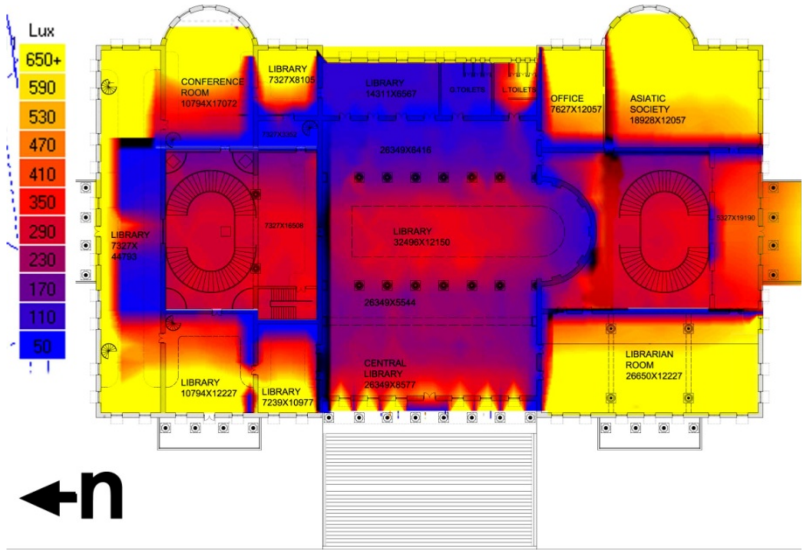


Figure 2 (a) Plan Main Floor Library (Padmashree, M. 2012) (b) Zones for daylight analysis (Authors).

Computer simulation of the luminous environment inside the town hall building was also conducted by using the software Autodesk Ecotect 2012. The available photographs and the drawings of the interiors and the sketches from the previous site visit helped gain extra inputs to the construction of the physical and computer model. The daylight measurement plane was set at 800mm form ground surface. Zones were formed according to the light typologies and were designated according to the function it carries. The zones demarcated is as follows,

Zone 1: The Hall, **Zone 2**: The library rooms on the south west, **Zone 3**: The Asiatic library office on south east, **Zone 4**: The Office areas on north.

The daylight studies were carried out by using Radiance a Radiocity based simulation plug-in for Ecotect which can provide more accurate simulation results. The daylight in the building is derived from three sources, Jhilmils, the windows on the walls, lantern light in the central Grand hall and skylights in the intermediate transition areas.



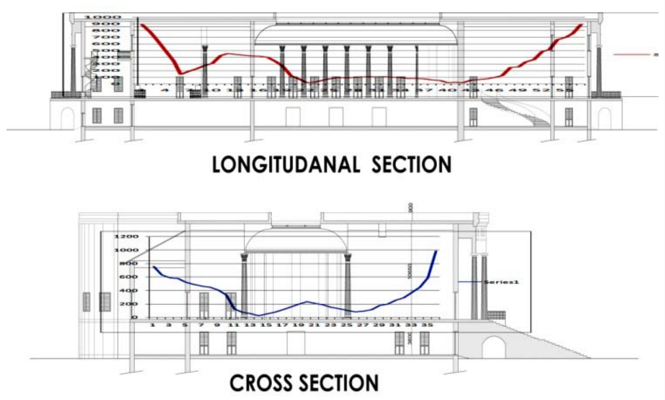


Figure 3(a) Isolux contour graph overlaid on the plan (Authors) (b) Sections showing the daylight factors over the sections (Authors).

READINGS AND SUMMARY OF DAYLIGHTING INSIDE THE BUILDING

The daylight distribution graphs suggest that the town hall was a designed as a daylit building and care was takes to see that all the areas receive daylight throughout the day. (Figure 3b)

Zone1-the hall is daylit by a lantern light at the roof level which provides sufficient daylight for the activities carried inside. It can be stated that the levels due to the elaborately designed skylight provides a lux level in the range of 100 to 120. Considering the area as public gathering hall, the lux levels can be said to be sufficient.

Zone-2 and Zone-4- the library rooms on south west are most likely to have solar ingress. The shading devices control the light levels and keep them in an acceptable range of 550lux. The area being designated to be used for reading purpose the daylight can be found adequate.

Zone-3and Zone-5 offices on East show a graph of lux levels which are in the range of 250-550lux. The use of the area is general office area and the light levels can be found to be adequate.

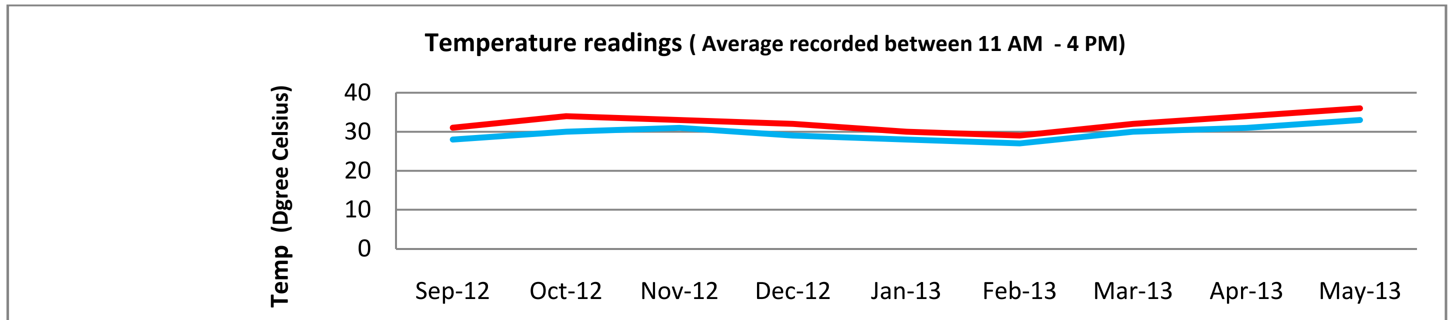
Zone 6, the intermediate and staircase areas are dominantly illuminated by the sky lights. They provide a lux level in range of 75lux to 120 lux. These areas are transition areas and the light levels can suffice the function.

The Window to wall ration (WWR) is less than 30% for all the facades which strategically controls the light and air movement. All the fenestrations have operable wooden louvered design further helping in controlled wind-flow and ventury effect for inducing cooling effect inside the building when required.

THERMAL BEHAVIOUR OF THE TOWN HALL

Thermal measurements were physically recorded on site to check the comfort factors of town hall. The temperatures inside and outside were verified at the intervals of 7days starting from Sept'12 to May-13. The set was averaged out to get an understanding of temperature variations inside the building. The temperatures were taken at a distance of 10feet outside the buildings on all sides. The internal temperatures were recorded at the grand hall, which falls in the centre of the building. The recorded temperatures show average of 3.5°C difference between external and internal temperature.

The major factor contributing to this temperature fall is raised platform directly facing westerly winds and colonnaded cooling like cross ventilation, shading devices, louvered windows, double facades on west and east sides, false ceilings and coffer ceilings on timber supported clay tile covered roofs seems to be still efficient through the noted temperature readings even though the building use has been totally changed. The wind movement has been induced merely by use of fans inside the building. But at the entrance porch, one can clearly feel the comfort provided by shade and the westerly winds. Also behind louvered windows the ventury effect is felt.



	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13
AVG External Temp	31	34	33	32	30	29	32	34	36
AVG Internal Temperature	28	30	31	29	28	27	30	31	33

Figure 4 Graphs indicating the temperature variations (Authors)

From above observations and readings it is to be noted that even the building use has been changed building still functions without active mechanical means of thermal comfort because of the passive design strategies thought at that time. Given a building is again used as public town hall, it can set a working and functional example for the passive building design.

CONCLUSION

The research can be concluded that the town hall building was not only designed in isolation but also the overall planning of the surroundings was considered. The building functions efficiently in terms light and ventilation without the use of any electrically operated active systems with its as designed functions. These techniques most likely used of compulsion are now a need of day. The methodology of analyzing the building used by the author can be helful for future studies on buildings which were designed in absence of electricity. The inferences and understandings for passive design concepts taken from such studies shall be incorporated in modern buildings for superior passive designs. These studies can help the contemporary building designers to strategiez the comprehensive energy saving techniques for modern buildings. This in turn would make noticeable change in perspective towards creating the energy efficient structures based on passive design strategies in energy guzzling metropolis like Mumbai. However the success of passive design strategies in building lies in the organized management and maintenance over a period of time.

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A Green School for Gaza: design and thermal performance evaluation.

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ABSTRACT

This paper describes the design and thermal performance evaluation of the first low carbon school building in Palestine. The project is a response to the mounting environmental, energy and infrastructure crisis within the Gaza Strip. The ambition is to provide a better learning environment for the children of Gaza, while also being self reliant in terms of electricity and water requirements. The project has been developed in close collaboration with UNRWA. The school, located in the Khan Younis refugee camp, will host 32 classrooms distributed on three floors for a total capacity of 2050 children divided in two shifts.

It relies almost entirely on passive strategies to achieve thermal comfort within the classrooms through the year. The roof is formed from a lightweight external 'parasol' shading a concrete deck below. Cylindrical concrete columns contain vertical ventilation shafts leading into solar chimneys at roof level. The classrooms are arranged around a large central shaded courtyard, which provides diffuse daylight and fresh air. The classrooms are naturally ventilated by a combination of cross and stack ventilation via the solar chimneys. The façade presents a high window-to-wall ratio and a series of large Mashrabiyas to reduce the incidence of direct solar radiation in the classrooms.

Dynamic thermal performance analysis evaluated the effect of the proposed strategies on temperatures in the occupied classrooms during summer and winter. The study concludes that mechanical cooling of classrooms can be eliminated, and that space heating demand is reduced to below 10kWh/sqm.yr. The residual electricity demand for lighting and power can all be met from the PV installation on the roof of the building. The project is currently under construction and the UNRWA intends to measure temperatures and energy consumption within the building and will report in a future paper on performance in-use.

INTRODUCTION

Gaza Strip is located in the Eastern coast of the Mediterranean Sea, bordering Egypt in the South-West and Israel in the East and North (figure 1). Since 2005, the area has been essentially isolated and the combined effect of growing population, polluted environment and unsustainable construction is questioning Gaza as a liveable place in the near future (United Nations, 2012). The expected increment in the population requires a review of the infrastructure required for electricity, water and sanitation to meet the future demand. Moreover, Gaza Strip is recognised as one of the youngest populations worldwide and currently presents a shortage of schools which barely responds to the needs of the population. This situation requires quick action and the efforts in education must be accelerated in order to maintain the quality of the education.

Figure 1: (left) Map of Gaza Strip and (right) image from the refugee camp in Gaza.

Concerned about the current situation in Gaza, the Kuwait School designed by Mario Cucinella Architects (MCA) and UNRWA aims to develop an off-grid building relying on passive design strategies and only locally available and renewable resources (figure 2). The design process was continuously informed by dynamic thermal simulations and computational fluid dynamic simulations in order to achieve thermal comfort in classrooms and enhance the performance of natural stack and cross ventilation.

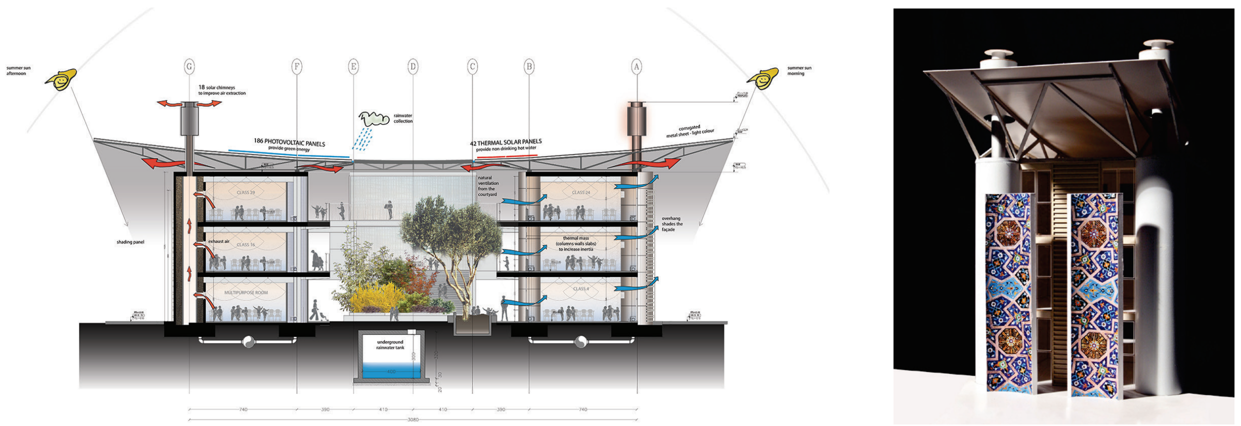

Figure 2: (left) Bioclimatic section during the warm period and (right) façade model of Kuwait School.

The first part of this paper will describe the different passive solutions adapted, including the building layout, solar shading, thermal inertia and natural ventilation; and will provide detailed information about the impact of each strategy on the building thermal performance through different parametric studies.

The second part of the paper will evaluate the overall building thermal performance during the year and will compare it with the standard constructions in Gaza.

The paper will conclude with a critical comment on the inmediate reaction required in Gaza and the potential of designing passive buildings in order to provide better environments and reduce carbon emmisions.

DESIGN APPROACH

The strategies adopted in this project are influenced by the weather conditions in Gaza, the current situation in the country and the building typology. An early climate analysis provided essential information about the risk of overheating, which is the result of an unobstructed building exposed to high global horizontal radiation, maximum average temperatures of 30C in June and September and high density occupied spaces (figure 3).

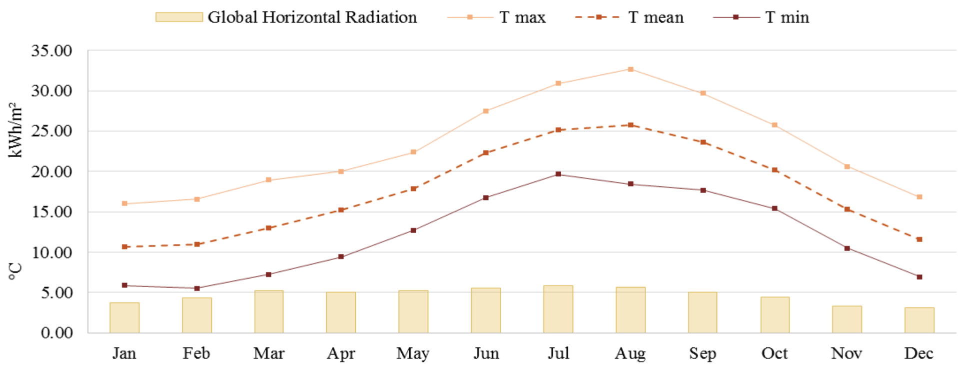

Figure 3: Mean monthly dry bulb temperatures and Global Horizontal radiation in Gaza. Source: Meteornorm.

The majority of the classrooms are 52sqm with 32 students organised in two shifts from 8-2 and 3 to 6. This becomes the main source of internal gains in the classrooms (46 Wh/sqm), still below the average in schools in Gaza (58 Wh/sqm) and the benchmarks suggested by CIBSE, 2006 (53 Wh/sqm).

Building layout

The classrooms are arranged in the perimeter of the building and around a large central shaded courtyard (figure 4). Under this layout the classroom can benefit from cross ventilation, diffuse daylight and fresh air from the courtyard.

Figure 4: (left) Building model – classroom layout and (right) shaded courtyard.

Window to wall ratio & mashrabiyas

The window design tended to maximise the effective aperture area to enhance the natural ventilation in the classrooms. The façade window to wall ratio is 0.38 whereas in courtyard is 0.43. Along the façade a set of mashrabiyas from the ground floor to the top floor reduce incident solar radiation penetrating the classrooms facing NE and SW by 35%.

Roof shading

A lightweight external parasol was designed to reduce the incident solar radiation in the top floor and at the same time provide shade in the courtyard. Dynamic thermal simulations helped to quantify the solar gains in the top floor classrooms for a shaded roof and an exposed roof. The excessive gains in the classroom through the exposed roof increases the internal temperatures achieved during a typical hot week in Gaza. The top classrooms can benefit by a 2ºC drop during the occupancy time by having a "second roof" (figure 5).

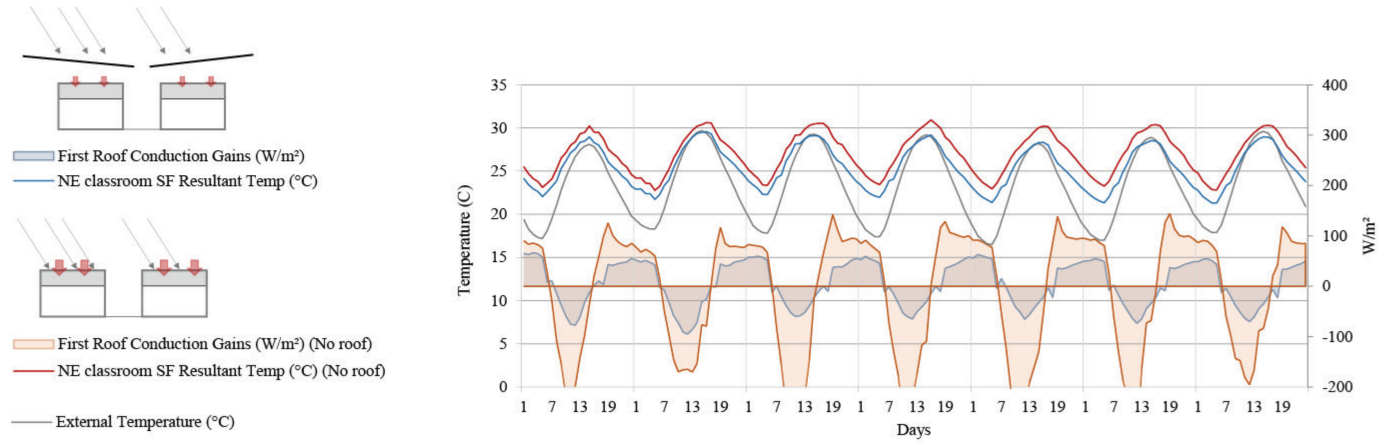

Figure 5: NE Classroom (2F) – Resultant temperatures and first roof conduction gains (Mon 4th – Sun 10th June).

Thermal inertia and building materials

An exposed heavyweight construction coupled with a night ventilation strategy was also adopted in order to absorb part of the high internal gains in the classrooms during the occupancy time and release the heat during the night. The façade is formed by compressed rammed earth blocks (density: 1800 kg/cbm; specific heat: 0.26 Wh/kgK) and the ceiling is an exposed concrete slab (density: 2400 kg/cbm; specific heat: 0.26 Wh/kgK).

Natural ventilation

The classroom layout, with openings facing the courtyard and façade, allows cross ventilation within the space. The typical air flow path is from the courtyard, across the classrooms and out through the façade. In order to enhance the average flow rate and provide the space with an additional natural ventilation scenario, a series of stack chimneys were designed to extract air. In rainy/noisy days, the classrooms can benefit from stack-cross ventilation with the façade openings closed. The grilles were dimensioned in order to extract the minimum required ventilation to ensure fresh air for 34 students. Each stack chimney extracts air from two classrooms in each floor and acoustic insulation inside the chimneys and noise attenuators in classrooms were applied. The top of the stack chimneys were designed with a high conductivity material which was proved to enhance the air extraction when it is exposed to incident solar radiation.

The apertures for each natural ventilation scenario were also designed according to the seasonal period and moment of the day (figure 7). During occupied hours in the warm period, the openings are considered with the maximum aperture, achieving an average of 42 ach in the classrooms. The non-occupied hours will be also ventilated and coupled with the high thermal inertia of the spaces by taking fresh air from the courtyard and extracting the released heat from the building elements through the grilles. During occupied hours in the cold period, an effective aperture of 20% of the total opening area will provide the minimum fresh air required to the space.

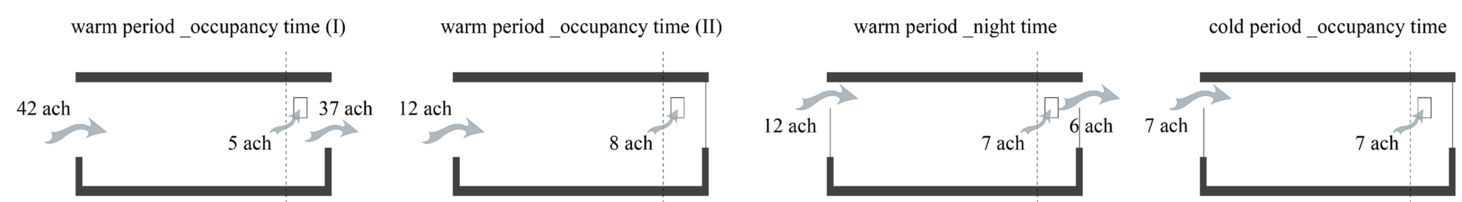

Figure 7: Natural ventilation scenarios and mean flow rates achieved in classrooms.

The air flow rates achieved in the classrooms will provide also a comfortable breeze that will create a cooling effect on the occupants. 2D computational fluid dynamics simulations were done in order to visualise the air flow path and velocities achieved in a section of the classroom. The cross/stack ventilation creates a minimum air velocity of 0.3 m/s, which crates a mean cooling effect of 1ºC according to CIBSE, 2005. This factor will increase the number of hours within comfort in the classrooms during the warm period.

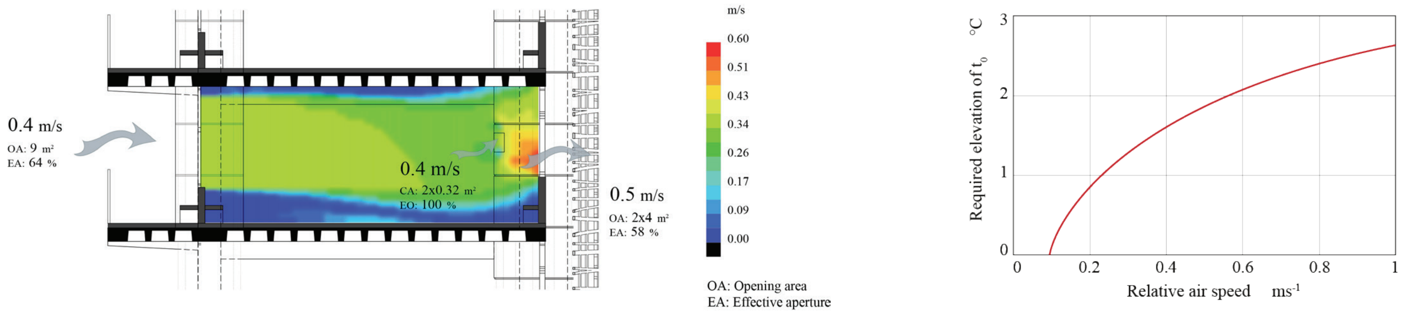

Figure 8: (left) Air velocity in classrooms - scenario I and (right) air movement cooling effect. Source: CIBSE, 2005.

OVERALL PERFORMANCE

Kuwait School

A final dynamic thermal simulation evaluates the overall building performance after the design process. A predicted comfort band using the European standard EN 15251 was used to evaluate the comfort conditions in classrooms during the year. The comfort band limits adopted for the cold period are 20-26ºC, and for the warm period 26-30ºC.

The percentage of hours during the occupancy time above and below these limits suggest that a comfortable learning environment could be achieved during the warm season (figure 9). The flow rates achieved during the warm period keeps the resultant temperature in the classrooms very similar to the external dry bulb temperature. A reduced temperature considering the cooling effect of the air velocity for each hour suggest that pupils could remain in comfort for most of the occupied hours.

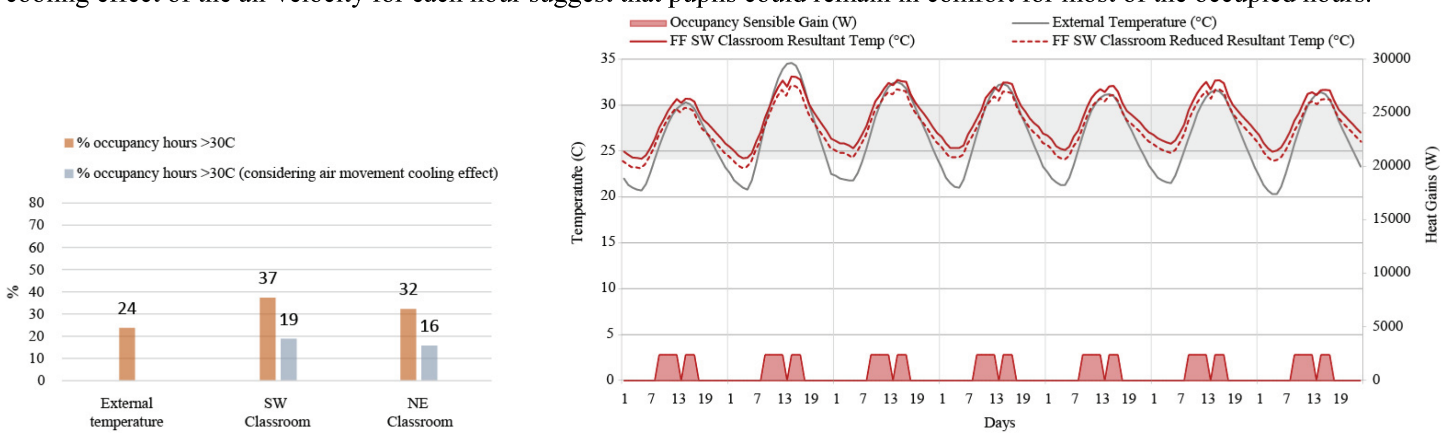

Figure 9: (left) Cumulative frequency of resultant temperatures in the warm period and (right) SW Classroom (1F) resultant temperatures - internal gains for a typical hot week.

The classrooms also present a good performance during the cold period mainly due to the high occupancy gains and the reduced ventilation flow rates. The equivalent heating loads for the classrooms remains below 10 kWh/sqm.yr after setting the thermostat set point to 20ºC. Mechanical heating is only required for the first 1-2 hours of occupancy (figure 10), same time when there is no incident solar radiation penetrating the classrooms due to the sun position and building orientation.

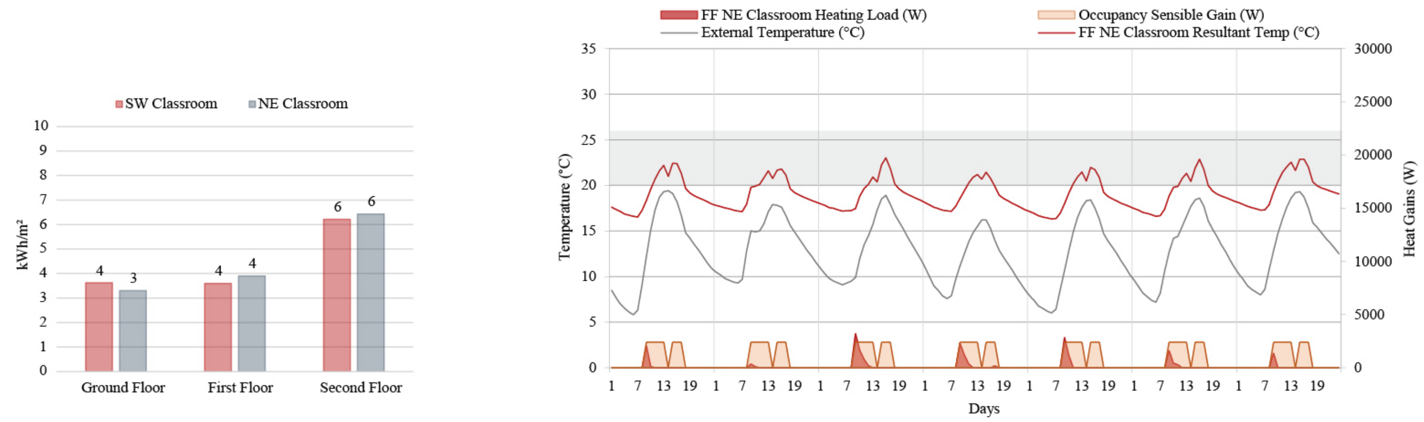

Figure 10: (left) Annual heating loads and (right) NE Classroom (1F) resultant temperatures – heating loads - internal gains for a typical cold week.

Common practice in Gaza

The current construction practice in Gaza is characterized by the lack of passive strategies adopted in buildings and a poor construction quality. This creates poor thermal conditions in classrooms and becomes the main reason for poor attendance in schools during the warm period.

A generic model with no passive strategies adopted was tested. An increase of 70% in the number of occupied hours within the predicted comfort band during the warm period was achieved with the final Kuwait School design, compared with the 'common practice' design (figure 11).

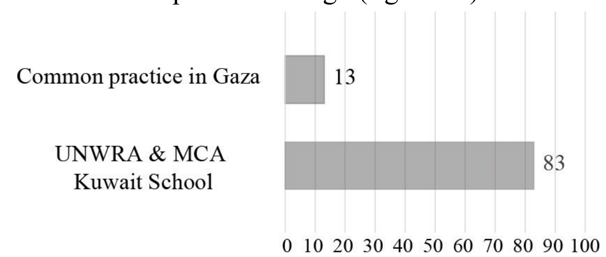

Figure 11: Frequency of occupied hours in classrooms within comfort during the warm period.

CONCLUSIONS

The environment, the climate and culture must be experienced first-hand in order to design bottom-up solutions for Gaza. Better buildings can be designed by taking advantage of local resources, but we all need to raise the awareness and organize information campaigns on the benefits of climate responsive buildings.

Natural ventilation can create a considerable benefit when coupled with the occupied space and adopting other passive strategies from the desing stage was proved to have an enormous potencial to reduce energy demand and carbon emisions and provide at the same time a better learning environment for the pupils.

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Session 4B : Low carbon cities and neighborhood development

PLEA2014: Day 2, Wednesday, December 17
8:30 - 10:10, Compassion - Knowledge Consortium of Gujarat

Solar radiation availability in forested urban environments with dry climate. Case: Mendoza Metropolitan Area, Argentina.

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ABSTRACT

The aim of this work is to advance the understanding of the solar potential of urban residential environments which, by their morphology, and the impact of urban trees, present values of irradiance that is very different from full solar collection. Morphological variables of urban settings and urban trees, a very distinctive feature of the Mendoza Metropolitan Area (MMA), have a fundamental impact on the feasibility of implementing strategies for solar energy utilization in urban environments. The results achieved will contribute, modify and gradually update urban and building legislation to implement higher levels of energy efficiency and minimum environmental impacts. This work proposes to study the potential of solar collection in urban environments, analyzing eleven urban configurations selected according to their building and urban morphological characteristics. Results obtained so far indicate that solar masking is critical for vertical surfaces, with a reduction of the available solar energy between 2% and 66% in the winter season. The first case corresponds to a high density homogeneous area, with wide street channels, at a third of building height, with little influence of surface shaded by the neighboring buildings and trees. In the second case, the impact of masking produced by the unleafed branches in winter is considerable and comes from species of first and second magnitude (10 m. high or more), constructions of low density and narrow street channels (13 to 16 m.). However, these drawbacks caused by urban trees are compensated by benefits in the warm season (Brager, et. al. 2001): controlling the intensity of the urban heat island, absorption of pollutants, cooling and humidifying the air through evapotranspiration, reducing thermal loads of buildings, occupancy of public open spaces, and an invaluable contribution to the urban aesthetic.

INTRODUCTION

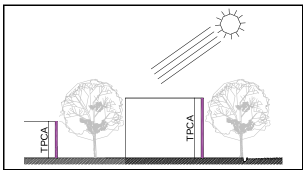
The present work studies available solar radiation on the North facades of highly forested urban environments typically of the Mendoza Metropolitan Area (MMA), as part of the environmental and energetically sustainable development of dry-land cities within Central-Western Argentina. The Mendoza Metropolitan Area is the most important political, cultural and economic urban setting of the whole MMA. Geographically, MMA is sited on the mesothermal arid region of the Andean alluvial plane, with coordinates at: latitude: -32.85, longitude: 68.86 and an altitude of 827 m.a.s.l. The region's main climatic variables are: DBT (min. yearly mean): .8 Cº; DBT (max. yearly mean): 32.30 ºC; RH (yearly mean): 56 %; Heating DD, (base 18 ºC): 1.384; Cooling DD, (base 23 ºC): 163; Annual hours:

in comfort: 21.53 %, heating needed: 70.14 %, cooling needed: 8.33 %; solar resource (4.58Kwh/m^2 day to 5.55 Kwh/m^2).
Regarding the relationship between habitat and energy, the unsustainability of the current development is aggravated by the fact that the situation inexorably deteriorates through time due to a lack of knowledge, management and planning actions. Some global figures are eloquent enough to describe it. At a global level, the habitat, which is the group of cities and buildings of the world, consumes 50% of the total energy used, leaving the other 50% divided into approximately equal parts between transportation and industry (de Rosa, 1988). Given this scenario, it is very important to take advantage of the natural resources and, in particular, to optimize access to the solar resource in order to diminish the consumption of non-renewable energy (Capeluto, et. al. 2003; Jenks, 1996; Owens S. 1986; Town and Country Planning Association. 1996). Given this concern, the following question arises: What is the impact of urban-building morphologies and of the different tree species that predominate in the urban environment with regards to the availability of the solar energy resource?

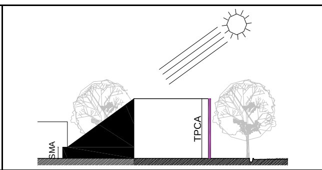
In the MMA, several specific studies have been developed, considering the representative groups of the urban-building morphology. These groups were determined by the solar potential in low and high density environments, which are highly forested. The objectives of the studies were: i. preserving the physiognomy of the forested city, maintaining the scale and homogeneity of the constructions and the aesthetic and environmental contribution of urban forest. ii: enabling the maximum use of solar resource for space and sanitary water heating, through the control of urban morphology and of the forest. iii: improving habitability conditions of the building area. iv: contributing to the sustainability of local development by enabling the recycling of existent constructions that were well maintained and of good quality. In this way, extractive processes and solid waste emission (rubble) in the ecosystem are reduced. In order to complete these studies, a solar irradiance measurement was performed on the North facades of 11 selected cases according to previous results. The intention of the study was to offer a contribution, both conceptual and operative, that through the transfer channel in the future, the official sector will become aware of the seriousness of the situation and soon begin to implement new urban and building norms that could also reduce the consumption of natural gas and other non-renewable energy in urban buildings.

METHODOLOGY

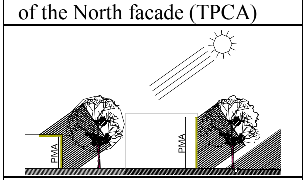
In previous works (Arboit, et. al. 2008) the Mean Insolation Factor (MIF) indicator was defined. Mean Insolation Factor (MIF) provides a measure of the potentially collecting North facing walls, not masked by neighboring buildings and trees, calculated as: the ratio of the sum of insolated collecting areas of North facing walls, times the sum of the energy received at each considered hour, during a heating season, to the sum of the total areas of the same surfaces, free of all masking, times the sum of the hourly impinging radiation during the considered heating season, as a percentage. Defined in Fig. 1.



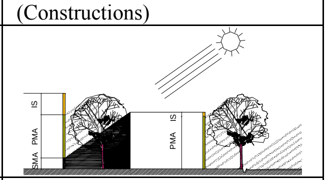
Total potential collecting area of the North facade (TPCA)



Solid Masking Area (SMA) (Constructions)



Permeable Masking Area (PMA) (trees)



Net Insolated Area (NIA): Addition of the values of insolated surfaces IS+ (PMA*P)

TPCA: Total potential collecting area of the North facade (m^2)
SMA: Solid Masking Area (constructions):
Potential collecting facade affected by shades projected by constructions of close buildings (m^2). (Figure 1)
PMA: Permeable Masking Area (trees): Potential collecting facade affected by shades projected by urban trees (W/m^2).
P: Monthly Permeability Factor. Solar permeability percentages of each vegetable species and for each month of the heating season (%). (Cantón, 2000)
R(m-d-h): Energy by surface unit available in the North facades for each hour, day and month of the heating season (Wh/m^2). Hourly impinging radiation on North facing walls for each month (Wh/m^2).
Sub-indicators:
m: Month of heating. It varies between April and September. Number of months to which the heating season is extended (n).
d. Day of the month. It varies between 1 and 30. h: Hour. It varies between 9:00am and 6:00pm.

Figure 1 Descriptive diagrams of TPCA, SMA, PMA and NIA.

$$MIF = \frac{\sum_{m:4}^{08}\sum_{d:1}^{30}\sum_{h:9:30}^{14:30}\left[TPCA - \left(SMA_{m-d-h} + \left(PMA_{m-d-h} \cdot \left(1 - P\right)\right)\right) \cdot R_{m-d-h}\right]}{NFA \cdot \sum_{m:4}^{08}\sum_{d:1}^{30}\sum_{h:9:30}^{14:30} R_{m-d-h}} \cdot 100 \quad (1)$$

$$MIF = \frac{\left[\exp(4.1969 - 0.1486\ St.Wi - 0.0127 F.Tress + 0.8547\ B.Morp - 0.4721\ TOF)\right]}{\left[1 + \exp(4.1969 - 0.1486\ St.Wi - 0.0127 F.Tress + 0.8547\ B.Morp - 0.4721\ TOF)\right]} \quad (2)$$

Considering the Mean Insolation Factor (MIF) on North facades and using a Multiple Linear Regression Model, the main variables that influence the access of the sun were determined (Arboit, et. al 2008). These variables are: Building Morphology (B. Morp.), Street width between construction lines (St. Wi), Fullness of trees (F. Trees) - relationship of the existing (healthy) trees around a city block to the total number of trees that could fit around the city block, considering the dominant species and their corresponding distance between individuals, as percentages-, Total Occupation Factor (TOF)-Total built-up area to total buildable area of corresponding parcels, as percentages-. (eq.2).

The easiest way to note the influence of the urban-building variables with access to the sun is by measuring global solar irradiance over the vertical plane of the completely sunny North facade and measuring the same variable of the facade that is partially sunny. The latter is affected by the urban-building morphology (building morphology, streets width, fullness of trees, building height). The measurements were carried out with portable irradiance data-measuring equipment that had a constant spectral transmission factor for all wavelengths between 0.3 and 60 μm.

The measurement period was established according to the latitude and longitude of the place of study, for a given day. Considering the local time, the solar noon was defined (≈ 1:30pm) and four and a half hours before and after the solar noon were taken into consideration. This approach left nine definite solar hours to measure from 9am – 6pm. Data was registered every minute during the month of July, August, and September of 2013. Based on what has been presented, the corresponding measurements were selected during a clear day for each urban environment. Clear sky conditions allow the evaluation, in its complete magnitude, of the influence of the trees and the urban morphology. Given that the measurements were realized during a winter period, the condition of unleafed branches has been evaluated. In this work we have utilized two irradiance sensors to evaluate each urban environment, one for the measurement of plain sunlight and another to register the shaded sections (Cárdenas, et. al. 2012). One must have in mind that in tree-covered urban environments irradiance can present important variations. In order to incorporate these characteristics it is suggested that a grid is drawn with two meters of separation and that a hemispheric photograph is taken towards the North at each corresponding point. In the hemispheric photograph one can overlap the sun trajectory to find the availability of the natural resource every hour of the day for that specific location in the environment. In order to calculate the received energy, one can apply a model of global irradiance on inclined surfaces (in this case 90º) that has been validated for different latitudes and climates. The proposed models for Liu & Jordan or Brichambaut can be appropriate (S. Benkaciali et.al 2012). In one of the case studies carried out in this work the application of hemispheric photographs is studied in order to implement this proposal.

Selection of case studies: For the monitoring of global solar irradiance in North facades affected by solid and tree masking, 11 cases were selected, in which different measuring conditions. For the selection of case studies, the urban-building and forestal morphology of the MMA urban environments was considered, based on the Mean Insolation Factor (MIF). On Table 1, the case studies and the characteristics of urban and building variables can be observed.

Table 1 List of urban and building variable values of the sample.

Cases N°	URBAN VARIABLES						BUILDING VARIABLES		
	Blocks		Street width (m)	Urban forest			Morphology	Front Setbacks (m)	Building Height
	Density	Orien-tation (°)		Tree Magni-tude	Tree species	Fullness of trees			
1	High	13	30.00	2^a	*Morus alba*	Several pairings	Regular	0	3rd
2	Low	4	13.40	2^a & 1^a	*Morus alba y Fxaxinius excelsior*	2 individuals	Irregular	5	1st
3	High	13	30.00	2^a	*Morus alba*	Several pairings	Regular	0	2nd
4	Low	5	16.40	2^a & 2^a	*Melia azedarach y Morus alba*	2 pairings/ Young	Regular	0	1st
5	Mid	5	16.40	2^a	*Morus alba*	Individual	Irregular	3	2nd
6	High	8	30.00	2^a	*Cupressus sempervirens*	Individual	Irregular	2	1st
7	Mid	7	14.20	2^a & 1^a	*Morus alba y Platanus acerifolia*	Several pairings	Irregular	0	2nd
8	Low	29	20.88	1^a	*Platanus acerifolia*	Individual/pruning	Regular	0	1st
9	Low	29	20.18	1^a	*Platanus acerifolia*	2 pairings	Irregular	0	1st
10	Mid	29	20.18	1^a	*Platanus acerifolia*	Individual/pruning	Irregular	0	2nd
11	Low	29	20.88	1^a	*Platanus acerifolia*	2 pairings	Regular	0	1st

ANALYSIS OF RESULTS

Figure 4 shows the diversity of energetic situations according to the analyzed urban environment and it shows a preponderance of each of the variables in equation 1. Measurements in shaded surfaces registered a reduction from 2% to 66% of the total energy received in the plain sunlight sections.

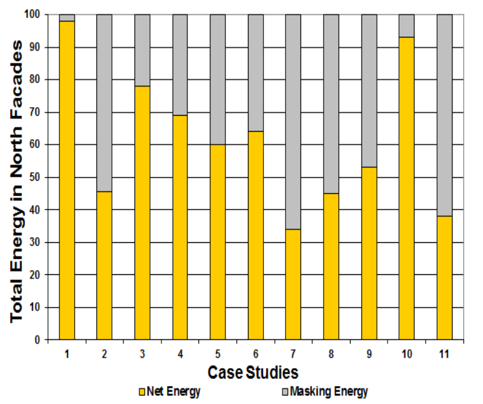


Figure 4 Total Energy %.

Total Energy in North Facades depends on the urban building environment; the 2% reduction corresponds to case 1 with an urban channel of 30 meters and homogeneous building morphologies that do not present shaded surfaces by neighboring buildings. In addition, its height is 10 m (with scarce influence of forest at the crown canopy level). The maximum reduction percentage, 66%, corresponds to Case 7, which is characterized by a wide street channel of 14.20 m, and the measurement surface is partially shaded by the forest at a second magnitude *Morus alba* and first magnitude, *Platanus acerifolia*, with the consequential reduction of the available energy.

For a more detailed study, Cases 1,2,3,6, and 7 have been considered, because they are urban morphologies in which each of the variables in equation 2 shows a well defined preponderance. In this way, the variables of *street width, fullness of trees, building height and morphology* will be analyzed and we will observe how they will influence the quantity of the received solar energy in North facades.

Influence of the Street Width: The street width and their orientation are decisive of the solar potential of urban buildings, in this case, although the direction E-W is the best orientation of the facade, and consequently, its best sunlight and maximum energy efficiency, the width of the 14.20 m street channel seriously affected the mentioned advantages. A narrow urban canyon when combined with the urban forest of first magnitude has a first order incidence in solar potential. The results of Case 7 indicate a 66% reduction of the available solar energy, the maximum reduction reached in this work.

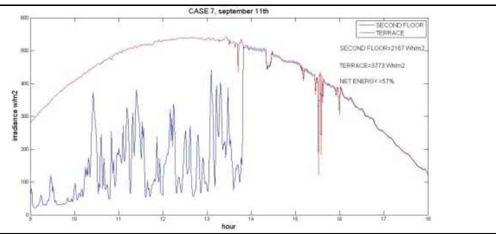


Figure 5 Measured irradiance in N facade, case N°7.

Figure 6 Views of the facade.
Figure 7 Trees seen from the sensor.

Masking produced by the unleafed branches can be considerable in winter, especially with species of considerable size (1st and 2nd magnitude and narrow street channels). In this case, it is observed (Figure 5) that the permeability that the trees in narrow urban channels offer towards radiation presents great variations according to the position of the sun.

Influence of Trees: In order to study how trees condition the access of the sun we have selected a case that presents the influence of two different species of deciduous leaves. When analyzing Figure 9, we see that in this case the reduction of available energy is 55% and that the influence of each species is very noticeable.

Figure 8 Environment.

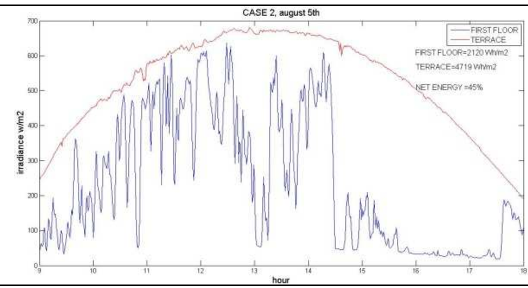


Figure 9 Irradiance measurement of the North facade, case N°2.

In morning and mid-day hours the reduction of the availability of the solar resource is 39% (Figure 10). This value corresponds to the *Morus alba* (species 1) bare foliage obstruction, while in the afternoon hours the resource reduction is 85% due to the high density of unleafed branches that *Fxaxinius excelsior* (species 2) presents (Figure 11). These results show that urban trees result in a first-order variable when capturing a solar resource in highly forested urban environments, and the choice of the optimal tree species at the moment of urban planning should be considered when contemplating future design strategies.

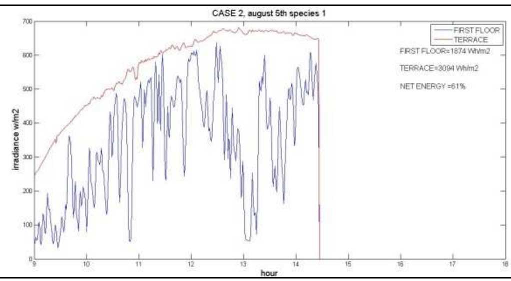


Figure 10 Irradiance measurement of the N facade, case N°2 (Influence of *Morus alba*, species 1).

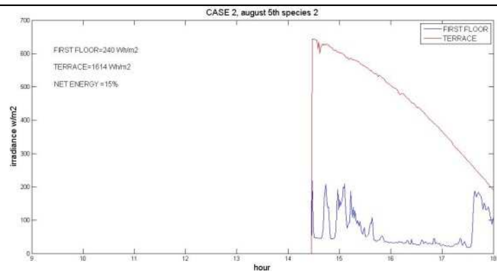


Figure 11 Irradiance measurement of the N facade, case N°2 (Influence of *Fxaxinius excelsior*, species 2).

Influence of Building Height: In order to analyze the impact of urban building morphology in relation to building height, measurements have been made by vertically displacing the sensor that measures the partially shaded zone of the facade. Figures12 and 13.

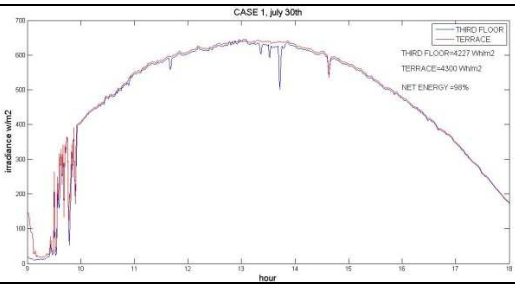


Figure 12 Irradiance measurement of the N facade, case N°1 (Third Floor, 7 meters high approximately)

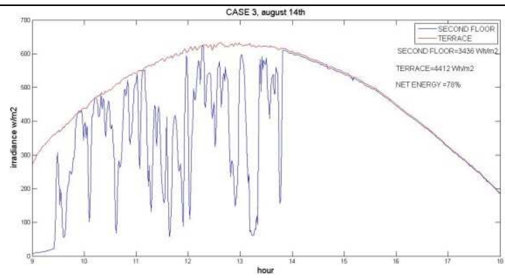


Figure 13 Irradiance measurement of the N facade, case N°3 (Second Floor, 4.5 meters high approximately)

Figure 14 Images of Case Study 3

98% of the total irradiance was available when the sensor that measures the partially shaded zone was placed on the third floor. Meanwhile on the second floor location, the measured values indicated a 78% availability of the resource. The difference between 2% and 22% (Figures 12 and 13), can be explained by the maximum development of the crown canopy of the existing trees of the North facade that reached a mean altitude of 10 m (Figure 14). The data, measured by moving the sensor in a vertical direction on the same facade, give us information to elaborate strategies that consider the conditions above and below the crown canopy of trees in order to maximize the use of the available solar resource in urban environments.

Influence of Heterogeneous Building Morphology: The solar potential in selected urban environments is determined by the aspects of the urban and building morphology, with different possibilities of interaction between volume and access to solar radiation. In this case 64% of incident radiation in the North facade is captured. The masking is due principally to the surrounding building morphology that gives shade to potential collecting areas, and to the permeable masking that the trees provide. With the goal of evaluating solid masking separately, Figure 16 depicts a graph. In the early hours of the morning and the afternoon there is a fairly small access to the available solar energy, the contribution is exclusively due to the diffused and reflected solar radiation components.

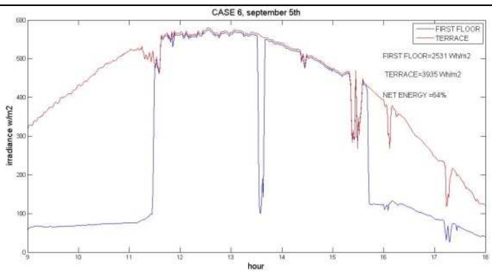


Figure 15 Irradiance measurement of the N facade, case N°6.

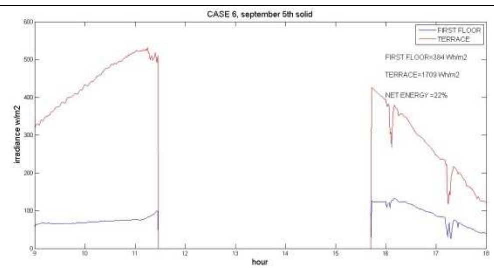


Figure 16 Irradiance measurement of the N facade, case N°6 (Solid masking evaluation)

When separately comparing the morning (16%) and afternoon (34%) availability, one observes that in the afternoon hours the reflected radiation has a greater impact due to the deviation of the urban outline's orientation with respect to the North (8° towards the East). One should have in mind that the important reduction of solar resource that this case presents should be much greater if the building morphology affects the access of solar radiation in the middle hours of the day. Building morphology has been considered in this analysis in terms of heterogeneity that generates front and rear overhangs, which produce solid masking, and compromise access to the sun. These types of heterogeneous morphologies are difficult to recover when implementing building recycling. When planning and designing new groups, the homogeneity is a basic condition for assuring full sunlight.

In this environment we studied the possibility of applying hemispheric photographs in order to complement the registered values. We made the comparison between the irradiance measurements (Figure 15) and a photograph taken from the location of the sensor oriented towards the North, and we overlapped the sun trajectory to the photograph according to the altitude and azimuth values that correspond to Mendoza on September 5th, 2013 (Table 2). Projection characteristics of the equipment used for obtaining the hemispheric photograph were considered in order to correctly locate the positions of the sun within the image along with the values of the sun altitude and azimuth. The equipment is a

Nikon camera COOLPIX 5400 equipped with a Nikon fisheye converter FC E9, which makes an equiangular projection according to what is shown in Figure 18 where the angle θ measured between the cast ray and the optical axis determines the radius r of a circle in the image circular view field where the pixel representing the value of the projected 3D point will lie (Havlena, 2012).

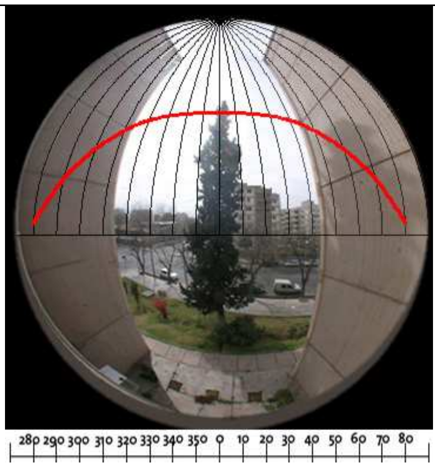


Figure 17 Hemispheric photograph of Case 6 environment taken from the sensor's location.

Table 2 Altitude and solar azimuth solar for Mendoza corresponding to September 5th, 2013.

HOUR	ALTITUDE	AZIMUTH
08:05	3,4°	80°
09:15	17,1°	70°
10:13	28,0°	60°
11:00	36,2°	50°
11:40	42,2°	40°
12:12	46,0°	30°
12:40	48,8°	20°
13:08	50,1°	10°
13:34	50,6°	0 °
14:00	50,1°	350°
14:25	48,6°	340°
14:55	46,1°	330°
15:27	42,2°	320°
16:07	36,4°	310°
16:54	28,0°	300°
17:52	17,4°	290°
19:00	3,7°	280°

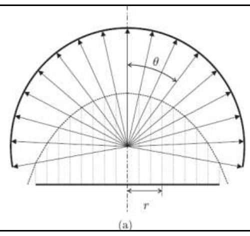


Figure 18 Equiangular projection of Nikon FC-E9 lens convertor.

Comparing the obtained measurements (Figure 15) and the photograph (Figure 17), one can observe that the reductions in the received energy that is shown in Figure 17 are produced at exactly the same time that the urban environment obstructs the access of the sun in Figure 17. This result indicates that, effectively, in order to understand the energetic situation of the complete facade, one could draw a grid with hemispheric photographs, overlap them with the solar trajectory, and apply a model to estimate global irradiance (e.g. Liu & Jordan or Brichambaut). This would achieve results for urban-building environments in a fast way and without the necessity of acquiring a number of irradiance sensors.

CONCLUSIONS

The obtained results give evidence to the impact of the principal variables that condition the access of the sun in a highly-forested urban environment. The eleven urban configurations that were studied in the Mendoza Metropolitan Area (MMA) present differential characteristics with respect to the urban and building variables. In almost all the cases, the solar potential of residential urban environments presents very different solar irradiance values (W/m^2) to the ones with full sunlight. The measured values of Mean Insolation Factor in the winter season fluctuate between a maximum of 98% and a minimum of 34%, due to solid and permeable masking (unleafed branches).

The important influence that bare foliage presents in winter has been demonstrated. These characteristics can be accentuated in certain forested conditions and under determined solar positions, as it is demonstrated by the measured values in Case Study 2, where afternoon hours recorded a resource availability of only 15%. These values suggest that there must be special consideration in the selection of species that will be structurally included in urban environments.

The heterogeneous building morphology strongly conditions the possibility of access to the sun.

This has been demonstrated in Case Study 6 where, during morning hours, a building with front and rear overhangs produced solid masking of up to 84% in its own North facade. It is worth recommending the homogenous building shape (that does not produce front and rear overhangs) in order to assure full sunlight on the potential collecting surfaces, as much vertical ones to the North in new groups as in existing groups where it is a basic condition for recycling.

The vertical displacement of the sensor that was used for measuring the irradiance of the partially sunny facade zone demonstrated the importance of establishing design strategies and legislation in accordance with a highly forested city that generates unique conditions above and below the trees. Furthermore, the influence of the surrounding buildings decreases when we consider greater building heights, as shown in Case 1.

The analyzed urban determinants for solar energy collection in North facades (trees, building morphology and building height), have greater intensity when they are combined with a narrow street channel. This situation corresponds to Case 7 where the minimum received solar radiation values are produced when considering all the hours of measurement. This determines that the strategies recommended for narrow urban canyons should be demanding with regards to the type of permitted tree species, maximum height of buildings, forms, and withdrawals.

The comparison made between the obtained measurements in Case 6 and the hemispheric photograph from the sensor's location suggests that, in order to quickly find out the energetic characteristics of urban-building environments, one can draw a grid of representative points of each environment and from each point of the grid obtain an hemispheric photograph, overlap it with solar trajectory that corresponds to time and place of the photograph and study the positions and hours of access to the sun. This information can be used as entering variables for an estimation model of global irradiance on inclined surfaces in order to find out the energetic availability of the environment.

The achieved results contribute to the progressive reforming and updating of urban and building codes in order to implement the highest levels of energetic efficiency and the minimal environmental impacts from urban buildings.

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Incremental Housing as a method to the Sustainable Habitat

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ABSTRACT

The manuscript discusses the research relate to the study of Incremental Housing models as a contribution to achieve sustainability in developing societies.

The slums as products of unsustainability and uncontrolled urban growth generate social disparities on the quality of life. These areas characterized by an organic morphology produced without rules results in a precarious and no minimum of housing standards. This situation contributes negatively to social development and has consequences in public health.

The research focuses the housing model that can be applied to promote the slums transformation and its integration in the formal urban area. The intervention model also allows the rehabilitation and improves the housing safety by regenerating the local activities to change the dynamics of unregulated development of the informal areas.

The integration and involvement of residents during the process was developed using participatory processes. This social integration component in the planning, housing construction and neighbourhood development allows to achieve the most appropriate solution to the needs and also reinforces the sensation of inclusion in the neighbourhood contributing to sustainable development.

The research findings are supported on the case study: The Slum Barruncho, Odivelas. The conclusions show the advantages of integration and participation of the population and make clear some of the choices made by the population for the application of vernacular construction techniques which had influence on the transformation model of the fragile environment.

INTRODUCTION

In all world about a billion people live in informal settlements (known as slums, *barrios, favelas*, *shantytowns*, or sspontaneous cities), number expected to double in the next 20 years. According to John Beardsley "Slums are now the dominant form of urban land use in much of the developing world". Ahmedabad, Buenos Aires, Caracas, Delhi, Bangkok, Mumbai, Nairobi, Rio de Janeiro, Sao Paulo, Mexico City, Cape Town, Dhaka, Kampala, Dakar, Manila, they are all fast-growing cities full of informal settlements, (Beardsley, 2007).

Interventions in informal settlements are a subject of debate throughout the world seeking how to integrate these areas in the cities that surround them. The interventions arise from many types of possible approaches, identifying two distinct groups by their initial nature. One based on total demolition and complete replacement of the area and the other in the transformation and requalification of these clusters through qualification strategies of the pre-existing. Following this last strategy emerges the Incremental Housing as a solution to a flexible intervention to the real needs of these areas.

Housing is a product of social, economic, political, and human realities. That thought gives us the perception that housing is much more than a consumer product, and may be understood as a process that helps building communities and be the roof for a fair and healthy society (Boonyabancha, 2011).
Following this thought Turner defended the "Housing as a verb", this is, housing as a basic need and necessary to enhance the aspirations to a better society (Turner, 1991). In a global scenario of shortages and fast developing is urgently design new ways of living that responds to the new paradigms of housing and his conception on the sustainability scenarios, valuing the inhabitant as the way of relation between the process, the product and the environment, (Canotilho, 2008).

Economically more viable, incremental housing has generated great interest throughout the world, especially when emerges united with social issues. This context allows the evolution and improvement of housing in medium-long term, giving better conditions of life for its residents without large upfront costs. The components are added or changed by inhabitants and/or builders as money, time, or materials become available. Are examples: the *Incremental Housing Strategy in India* (2008) the *Elemental in Chile* (2003); and the *Aranya Community Housing* in India (1989). The *Incremental Housing Strategy* (Smith, 2011:pp118-119) in India stands out for the community participation in the preparation of the Yerawada revitalization strategy, where the purpose solution was the increase of the number of housing units, according to the needs of each family, respecting the organization model of the existing neighbourhood regarding the pre-existing pathways, on the integration of new constructions on the mesh already built. The implementation of this project contributes to a better quality of community life at several levels (the project enabled the sanitary installation in every home) and also to the quality of urban space and territory. According to Filipe Balestra for this process be considering an effective sustainable project the improvement of existing housing has to be done based on a real community participation (Balestra, 2008).

Another example is the *Elementar* by Alejandro Aravena, where the project is based on performances over bounded communities, through the establishment of housing projects that intend to an appreciation over time taking into account housing not only as a habitat but as a mechanism for the family investment. The family begins with the base and wins motivation for their continuity through creative solutions for the community housing needs, according to a sustainable base and local economy. The *Elementar* defends that communities themselves promote their constructions and economy who have impact in the social improved stability and in the vision of a city equal for everyone. It was concluded that give the residents the possibility to adapt their "homes" to their true needs and lifestyle, allows safeguard the housing and adapt their functioning to the actual needs and at the same time allow them to create a strong sense of belonging and identity (Aravena, 2013).

The *Aranya Community Housing* started in 1980 in the city of Indore, with the aim of creating incremental housing for critical areas of the city. To each family has been provided a small lot with different infrastructure according to its financing capacity. The plot could contain a complete housing or the minimum surface area to build one house. The project started with a strong analysis of the urban morphology and behaviours of the local population (the streets organization, the houses, the various types of aggregation) reflected on the participation of the residents. The project shows that after 30 years houses continue to evolve and grow, physically and aesthetically reflecting the user's needs and the capability to generate solutions to its inhabitants. The neighbourhood became very busy, providing an attractive environment for its residents and visiters. *Aranya* is in many aspects the validation of the ideals of incremental housing applied on a critical area in urban expansion.

The concept of Incremental Housing is based on the capacity to adapt the house model to the evolution of the family (growth and decrease of the number of family members). However it is important to assure that it is available to adapt this evolution of the housing to the site and urban context (Neves, 2013).

Coelho and Cabrita discusses that the process of incremental housing is directly connected to the family evolution,"(…)*embracing forms of gradual improvement and adaptability to the changes, more or less successive, of their inhabitants lifestyles, may so, ensuring the progressive realization of the "housing desires", as they are being made and discussed by locals and chosen as real objectives to be attained at a certain time in these homes*."[1] (Coelho & Cabrita, 2009: p.11).

According to Portas and Silva Dias in the study "Incremental Housing", the main quality of incremental housing is the capacity to build a system based on simple rules of design and execution, able to define the first phase of installation, promoting qualitative evolution of the home environment and others areas, essential to next inhabitant's sociocultural evolution (Portas & Dias, 1972: pp.100-121). This concept ensures that the improvements of housing are according to the capacities and investment funds of each family.

Coelho and Cabrita also claim that some operating characteristics of the standard or inflexible housing make it impossible the continuous evolution and improvement of housing: spaces designed with only one function; inadequate fixed equipment; windows designed for rooms with specific function; proportions of compartments related to certain functions; narrow access and circulation; and the existence of only one access to the outside (Coelho & Cabrita, 2009: p.12). To avoid such difficulties it appears necessary the establishment of a minimum set of initial requirements, from which it will be possible to develop housing in a healthy manner.

The "incremental process" isn't just a solution or an approach; it contains a large number of invariants through several volumetric increase forms and miscellaneous modalities of development, improvements and finishing of housing, being some more appropriate for single-family and others for multifamily housing. In a general way it's possible to integrate the various models of evolution on three forms or principles: aggregation; expansion and division (which could act in an isolated or combined form, and appropriate to each individual case). These models should be studied in the project design phase in order to achieve stability during the differents stages of development.

It is also important to ensure the integration of incremental housing at the urban level and have in all the urbanization physical structures adapted in order to integrate the housing development. Following this issue Portas and Silva Dias argue that urban integration of an incremental housing solution have at least two possible actions: one of functional nature relating the population economic and social behaviour; and the other of visual nature (spatial) linking the neighbourhood image and its morphological relationship with the city (Portas & Dias, 1972: pp. 100-121).

A solution that allows adapting the evolutions to the urban plan is its application in each phase, actions to ensuring the continuity whit the surrounding through a gradual improvement throughout the stages. Also the self construction integrated in the planning process with the population contributes allows create an application model that guarantees the essential of the self-governance by the population without going into ruptures between the inhabitant, the house and the public system (Neves, 2013).

Participatory process

The rehousing process involves significant change and requires a profound restructuring of daily life and its practices related not only the residential behaviour but also in transport, leisure and recreation, neighbourhood network and makes compulsory needs in the adaptation to the new living form of the residents (Portas, 1995). However, it is relevant to refer that the space appropriation whether it be of the territory or of the housing itself, is an important step towards the creation of an identity bond between the space and its inhabitants.

During the rehousing process, the housing living space appropriation and the public space are important aspect because we face a process that can break with previous modes of life, and required and rethinking of the space appropriation form and the established identity relations. It is necessary value the dimensions of appropriation, embeddedness and identity that happened through housing appropriation

[1] Translation by the author.

and consequently the neighbourhood since only in this way we can ensure a positive relocation and the safeguarding of existing housing and neighbourhood spirits.

Herman Hertzberger defends the need for the participation of the population as a condition *sine quanon* for a perfect future space appropriation. For this author that should exist reciprocity between the shape and the use and the experience for different people and different times. This involvement and participation should follow the whole process of evaluation from the planning to the implementation (Hertzberger, 1999).

Christopher Alexander also states that "*the only way to build forms that are loved by its inhabitants is through their participation in the process. The mere fact of an individual participating in the planning or construction of his home or neighborhood establishes a connection between him and the realized object. (…) Most people don't have the least concern for formal design virtues, they just want something that they can truly consider theirs.*"[2] (AAVV, 2006:p.28).

METHODOLOGY

This research involves a sequential methodology that requires the use of large transverse scales (focusing in the case study - Barruncho) for searching and proposes an intervention action into the surrounding urban grid.
It is important to the intervention in these informal settlement to have a complete understanding from the urban reality at the municipal level to the scale of the place (including the urban grid, infrastructural systems and accessibility, social and economic activities, conditions and ecological implications) to provide a complete systematic characterization of the site. This clear understanding of the territory in its differents aspects turns as a starting point for defining the future approach and subsequent assessment of global impacts of continuing the isolation at the neighbourhood level; the planning development of the surrounding urban grid followed by the elaboration of the premises based on interventional leadings towards the development of the case study as astrategic option. The applied methodology promotes also an incremental module house built with sustainable materials and from an adaptive house design which the implementation in the territory results in the definition of a concept of balanced spatial and functional organization for local intervention. This process composed of variable and invariable parameters allows the construction of a final solution possible to application at any socio-economic and territorial context adapting it to the variable parameters for each context (Culture, family, climate, housing type – **see figure 1**).

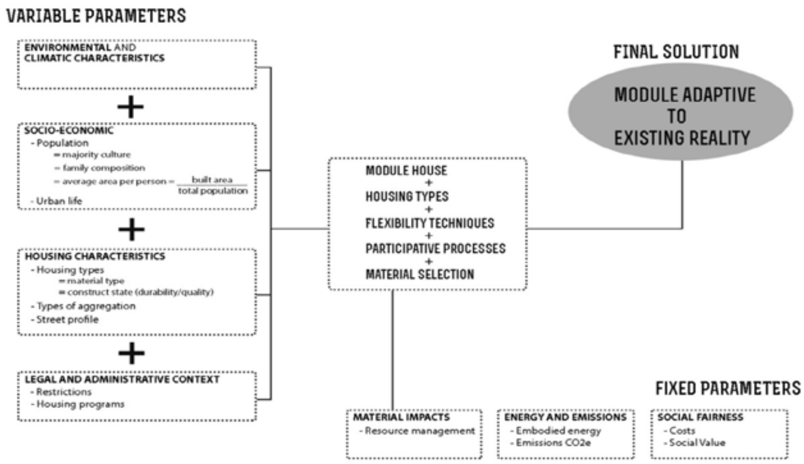

Figure 1 Design concept methodology diagram.

METHODOLOGY APPLICATION AT BARRUNCHO CASE STUDY.

The Barruncho neighbourhood is a primordial study subject because it is a critical area that

[2] Translation by the author.

highlights the greater number of typical slum houses in Odivelas city, Portugal. The need for an urgent intervention results not only as an urban issue to promote the urban consolidation, but alsofrom the need to solve the social anthropological context. The crime settles and develops quickly in these settlements, who show that the greater the degradation of the same the lower results in promoting social and cultural integration of its inhabitants. The analysis shows to us the necessity of an imminent intervention and the clear understanding that the complete destruction of the settlements and scattered rehousing of its inhabitants is not always the most viable and effective solution.

Parameter 1: ***Barruncho environmental and climatic characteristics***

The environmental and climatic analysis are important in the development of an efficient and sustainable housing module, and should be taking into account in the process since the location decision to the selection of construction materials. Barruncho's climate is a mild climate, Mediterranean, mild wet and moderately rainy, presenting maximum temperatures with average values in the order of 22.5 ° in July and August and an average relative humidity between 63% and 82%, revealing potential for agricultural activities. The mild climate and good sun exposure will determine the passive design conception and material selection, focusing the seeking for renewable energy sources and ensuring quality housing with thermal comfort. The orography (ratio between hydrography and topography), Barruncho arises as a natural amphitheatre that enclose the houses west side bounded by a water line marked and with orographic peculiarities which regulate the delimitation of streets and paths according to the verified slopes.

Parameter 2: ***Barruncho Socio-economic***

The Barruncho population is heterogeneous in cultural and ethnic terms, being composed mainly by Portuguese, Africans and gypsies. There is a great predominance of inhabitants born in Africa (PALOP – Cape Verde [41%]). Barruncho have about 540 people, distributed by approximately 115 households with and average size of 4,7 people. The reality reflects a large number of households consisting only of 2, 3 and 4 elements. In general, the population has low or no academic qualifications. The data reveals the poor education of the older generation and the high percentage of young people that are still at school age. The Barruncho is characterized by its strong neighbour relations and it is based on these relationships that most of the population develops its activities.

Parameter 3: ***Barruncho Housing characteristic***

With only one floor level with lower ceiling height, the dwellings define precarious spaces with reduced interior areas. The dwelling starts with one compartment (where all house activities are done) and as it is possible and necessary evolves, increasing the number of compartments. Lack of space linked to the inhabitants needs requires flexibility of spaces functions in the interior of the housing. The interior of the housing is the place where are developed the main family activities. The construction materials are diversified and sometimes creatively solution as been applied. The most used materials in construction are zinc sheets, adobe brick, wood beams, MDF boards. As coverage material predominates the metal sheet, existing in smaller quantities fiber cement sheets, tile (associated with the pre-existing neighborhood buildings) and some mixed materials covers (plastics, tiles, plates). The current application of organic materials without a preliminary study with a long-term strategy (more durability and quality, less maintenance) is a very precarious solution.

Parameter 4: ***Barruncho Legal and Administrative***

The legislation and regulations can be useful and applied to the study case as an important tool for the concept design since they establish the minimum standards required. However, to transforme an informal settlement is important to consider more than the minimum legal standards. It is required the perception and adaptation of theses measures according to the population real needs (culture) through good sense decisions.

In 2008 the Town Hall of Odivelas declared as *Critical Area for Recovery and Urban Reconversion* (ACRRU) the site of Barruncho, because the profound social and urban decay observed in this area. The methodology results in a construction model applied in Barruncho that is capable to solve the housing problems and create positive impacts at environmental, economic and social levels: “Cradle-to-Cradle posits that mankind can have a positive, restorative, beneficial impact on the environment.” (Cradle to Cradle Products Innovation Institute, 2013). The model is associated with a modular incremental housing concept that presents economic and environmental advantages. The standard incremental house concept allows an optimization in terms of costs, construction time, and resources management but also in a design strategy that suits the Barruncho social dynamic.

Module Composition - Based on the analyzes conducted both to population and the settlement itself, was calculated the average area per person (area required for this specific population) and the average number per family unit (there is a large percentage of households with 2 to 4 elements) which originates two adapted and evolutive base modules. One (module A) with an implantation area of 55.3 m2 and one patio of 11.7 m2 that allows the evolution by expansion and other (module B) with 60.3 m2 implantation area plus a small patio with 17m2. In this way, the designed strategy of incremental housing focuses on a modular logic, where the base module is not repeated by mere overlay, but occupies different positions in space, generating different types of aggregation based on major "existing" typologies currently at Barruncho. The application of these new modules in a phased process allows to create a more ruled settlement appearance, without jeopardizing its identity to avoid the “shock” associated to an abrupt change that is typical of common relocation situations and allows at the same time solves the problem of where to accommodate the population during the execution of the work. The incremental process is done according to the overall intervention plan (roads, streets, access, areas of public space and equipment), and taking into account the condition and construction quality of current housing, replacing first the most urgent housing. The phasing implies addition to replacing the “existing tents” by the new housing modules, the gradual improvement of public space through new reception areas and gardens, the creation of a central square which will host small commerce activities, as well as the development of housing. Phase I evolves into a phase II and simultaneously to a phase III until the whole settlement is rehabilitated. This sequential process ensures a component of evaluation and monitoring that allows plan adjustments to changes in initial premises.

Module A. This module was designed to develop by expansion. The base module (to a couple) is constituted by a social area, a private area and an outdoor area capable of evolution (an outdoor patio). The dimensions of the social area were carefully designed not to be too “big” at an early stage, which could result in a misappropriation or in an uncomfortable space; neither too “small” in a more advance stage, ensuring an adequate area to a larger number of inhabitants. In first phase of evolution, due to the household increasement or the need for more area, the base module evolves by expansion, through the construction of a second room in the zone previously designed for this evolution (patio). In a second phase a staircase is built in the second room, which will give access to an upper floor built in this phase where new rooms will be built as required. At this stage, the rooms offer flexibility strategies; being fixed only the exterior walls and the sanitary area. At last, when the household decreases or the children get married and need their own home, the lower floor access is closed and transformed into an independent access, turning the two floors house on two houses with independent accesses allowing through the evolution by division that the house always accompanys the household changes (**see figure 2**).

Figure 2 Module A evolution scheme.

Module B. This typology more rigid in terms of the module's physical limits (doesn't evolve by expansion) but the interior is more free and flexible and can be changed and adapted to new needs, allowing to develop by division (transformation into two independent modules). The concept goes through keeping fix the "wet areas" and allowing that the rest constituting the free plan, able to host some of the space flexibility desired, through walls-cabinets (cabinets that stretch from floor to ceiling turning into divisions); fake-walls; folding walls. Thus the spaces are open to changes at function level, punctually in area and sometimes through the day (egg. at daytime one division is a living room with sofa; at night the sofa becomes a bed), (**see figure 3**).

Figure 3 Module B evolution scheme.

Material Selection

The adaptability to the family needs is the objective of Incremental Housing It is important that its constructive system be accessible. Thus, the modules were designed allowing its construction by two people, due to its simple geometry and easy materials application. The materials choice also consisted in the identification of materials according to the principles of Cradle-to-Cradle: natural and local materials with low environmental impact (low emission of C02 e/m^2 and embodied energy); economically viable; recycling potential and compatible with local population culture and know-how. According to the territorial analysis, the most common and environmentally effective material in Barruncho housing is the adobe brick. However, due to the advantages and the easy access to land as raw material, it is proposed the use of Compressed Earth Bricks (BTC). The manufacturing process is fast and doesn't need an oven. This allows a production with natural resources and almost with no transport efforts, reflected in cost reduction. The earth construction is an easily adaptable and teachable technology that allows unqualified people to learn a skill, increasing social values and creating and opportunity for local business. Based on Cradle-to-Cradle model, the embodied energy and emissions calculation is an important tool for material sustainability and efficient evaluation about the harmful gases emissions and energy consumption. According to the evaluation by *Auroville Earth Institute*[3], the BTC are about four times less pollution and spend about four times less energy than normal bricks (**see table1**).

Table 1. Sustainability and Environmental Friendliness of BTC

Initial Embodied Energy per m3 of wall	Pollution Emission (Kg of CO2) per m3 of wall
BTC wall = 631MJ/m3	BTC wall = 56.79 Kg/m3
Kiln Fired Brick (KFB) = 2,356 MJ/m3	Kiln Fired Brick (KFB) = 230.06 Kg/m3
Country Fired Brick (CFB) = 6,35 8MJ/m3	Country Fired Brick (CFB) = 547.30 Kg/m3

Note: Kiln fired bricks are often called wire cut bricks. (Unesco Chair Earthen Architecture- AVEI)

CONCLUSION

Housing is perhaps the biggest problem of actual societies since it is a basic human need. But, the

[3] http://www.earth-auroville.com/ (May 2014)

society not always has secured the access to this fundamental human right.

For long time we have seen several cases of social housing where the only purpose is to accommodate the greater number of people in the most economical and easy way, opting for a standardizer construction aggregated in height or disposed at a ruled mesh without being thought to the experiences of the people (neighbourhood networks, sociability and culture).

The fact that urban projects are created as dorms and not as qualified urban spaces which assume the existence of a complex sociability network makes it important to provide different spaces that dynamize the neighbourhoods experiences done by an incremental social housing with support on participatory processes as a positive result. It's necessary to rethink how it can be promoted the population involvement along all the rehousing process. In result the potential of Incremental Housing as a possible solution to housing access, inserted in a participative planning process with the population knowledge and involvement are a successful solution.

From the reality of Barruncho project, it is possible to understand the importance of the population and its territory, on a situation of in-situ rehousing; creating an intervention appropriated to the existing reality without rupturing with the population memory neither with the way of life. Involving the population in the house construction and change of the neighborhood morphology enables the adaptation to the population real needs and develops the strong sense of belonging and affection which is fundamental to the well-being of the residents. The use of onsite materials is an affordable and environmentally sustainable solution; reducing transport, fuel and construction costs and providing work opportunities and local economy. The reduction of embodied energy is a goal to be observed in every step process

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An ENVI-met Simulation Study on Urban Open Spaces of Dhaka, Bangladesh

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ABSTRACT

Artificial constructions dramatically modify urban geometry, which has a direct impact on urban climate. This study takes a simulation approach to analyze the impact of urban geometry on urban micro-climate in residential area during summer season in Dhaka, Bangladesh. Two environmental factors, air temperature and air velocity have been selected to quantify the outdoor micro-climate. This paper reveals that urban open spaces can improve the surrounding micro-climate as it has a significant cooling capacity. It directly controls the electrical energy consumption as domestic usage demands the highest energy consumption in Dhaka. So, urban open spaces are important to reduce the urban energy consumption. This study also shows that urban geometry has a strong impact on the park area and buildings with minimum ground coverage performs better than that of maximum ground coverage both in lowering the ambient temperature and increasing wind flow. This study reveals that building grouping can also create marked impact on the micro-climate. Therefore, there has to be specific guidelines regarding building geometry and grouping of buildings, so that the microclimatic condition of Dhaka can be improved without any extra intervention. So, when deciding Floor Area Ratio of a particular area, the existing situation has to be studied as the local environmental data are not similar with the MET office data. Then on the basis of those microclimatic data, the design decisions has to be generated to get the best result of urban open space in terms of environmental benefits.

Keywords: urban geometry, urban open space, ENVI-met, urban micro-climate

INTRODUCTION

Cities have produced the most notable man-made changes to the ambient climate (Landsberg, 1981), (Oke, 1982). Three dimensional characteristics of the urban form, surface material etc affect the environmental factors characterising a climate (Ahmed, 1995). Ensuring outdoor comfort is an important part of the urban design agenda. Urban open spaces are essential components of urban design in Tropics where increasing built density is resulting in inadvertent environmental modifications (Ahmed, 1995). Urban morphology interacts with people behaviour and the local climate (Goulding, Lewis & Steemers, 1986). The structures within the urban canopy exert a strong influence on the urban boundary layer wind and thermodynamic structure at the neighbourhood scale (Goulding, Lewis & Steemers, 1986). Dhaka, the capital of Bangladesh, lies between 23º 40´N to 23º 55´N and 90º 20´E to 90º 30´E. Vegetation and moist soils characterize the land, which is flat and close to sea level (Hossain, 2010). Recently, high concentrations of various types of buildings and built spaces are observed in Dhaka (Hossain, 2010). These buildings are regulated by National Building Codes, which provide guidelines chiefly about setback of the buildings, floor area ratio (FAR), height and also speak about mandatory open spaces, parking provisions etc. There is a significant temperature gap between Dhaka city centre and fringe areas which indicates to an urban heat island effect (Mojumder, 2000) and poor energy performance of its built environment. To achieve a thermally agreeable environment, promoting urban design approaches, relying on the natural cycles, can be an important step towards achieving environmental sustainability in tropical countries (Ahmed, 1995) like Dhaka. So, at the stage of policy making and site planning, the issues of ensuring outdoor comfort relying on passive control should be an important element in the urban design agenda.

PROBLEM STATEMENT

Urban form, land use, presence of natural geographical structures etc have significant effects on microclimate of an area. The Urban morphology includes the street pattern, built density, insufficient green space as responsible enough in creating urban heat island effect within a city (Smith & Levermore, 2008). Urban vegetation influences urban climate as it helps to control heat gain, mitigate urban heat islands, produce shadow and also reduce noise levels. The proportion, of the street and building geometry, controls the solar heat gain (Smith & Levermore, 2008). The intra-urban temperature rises, the wind and ventilation characteristics are greatly modified by the surroundings. The daytime canopy layer of heat island is of most interest to urban designers as it is largely due to design and hence is within the scope of control of the planners. According to World Bank, Dhaka bears the distinction of being the fastest-growing megacities in the world and the city itself is growing at a rate of 4.5% per year (Circular Waterway around Dhaka City, 2006). The Land use pattern of Dhaka shows that the agricultural land is high but all at outside of Dhaka metropolitan. The city is now expanding at the cost of agricultural lands and forests. As a result, there are very limited green open spaces in Dhaka city (Hossain, 2010). Among the built areas (without agricultural land) residential land is the highest (27%) in area. About 85% of the national energy demand of Dhaka city is used for the Domestic usage (Hossain, 2010), hence heat generated within the residential areas should be reduced. The temperature of Dhaka varies with morphological (buildings, roads, green parks, water body and others) character of the city (Ahmed, 1995). The hard surfaces of roofs and roads gain more heat and are the cause of urban heat island effect (Hossain, 2010). Designing building in such a compact and high density context is challenging. Passive design techniques and simulations that do not take into account the micro-climatic conditions of the site, are unlikely to be satisfactory. The accuracy of weather data files used in building simulation design packages depends on the site typology, its landscape, method of meteorology measurements and the time period of years (ASHRAE, 2005). The microclimate can be controlled through proper developing of the morphological components which also controls the energy consumption (Hossain, 2010). By studying the impact of the building geometry on urban open spaces of Dhaka, ways and means of moderating the physical development can be identified to improve environmental conditions. This study observes the impact of park on the adjacent areas and vice versa. To develop a relationship, between urban open spaces and urban geometry of the surroundings area, the impacts of various urban geometries of buildings in Dhaka have been investigated by simulation analysis in the summer season.

METHODOLOGY

Literature reviews have been done to gather knowledge about city morphology and climatic context of Dhaka. To establish allowable building height according to FAR, the 'Building Construction Act 2008' has been analyzed. The study was conducted through analyzing the Simulations of temperature and wind flow, two environmental factors quantifying outdoor microclimate, of an imaginary location in the climatic context of Dhaka. The parameters of the temperature and wind velocity are simulated using ENVI-met software in April, the most hot and critical month of the year. Firstly, the impact of a park area on the microclimate have been analyzed by comparing three different scenario of having a building, a road and a park on the same plot. Secondly, the impact of surrounding building geometry (with Maximum and Minimum Ground Coverage) on the park area has been investigated into three broad categories of building geometry, depending on the common practice at Dhaka. The simulation approach, using ENVI-met, has been increasingly adapted in urban climatology studies. ENVI-met is a CFD numerical model that is capable of simulating complete built environment surface-air-plant thermal interactions based on the fluid dynamics and heat transfer fundamentals. In this paper, it is used as meteorology generator to assess the impact of different building geometry on the park.

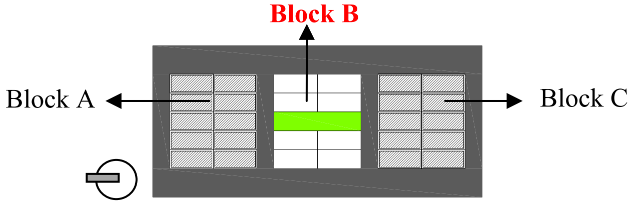


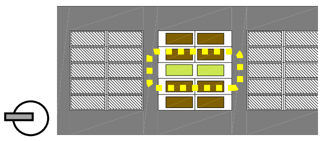
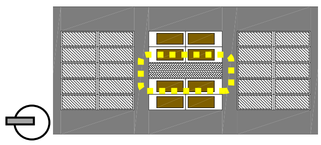
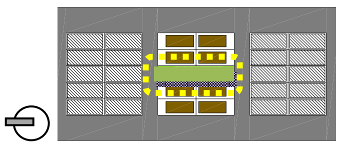
Figure 1 Site condition (Conceptual)

A situation of residential area of Dhaka was selected as a case study area, **as shown in Figure 1**. Two 30m wide roads were there, on the east and west side of the three blocks named as A, B and C, and two 18m wide roads were also on the north and south , Block A and C, both were residential blocks each having 10 plots (46m by 20m each). Now, for each Plot of Block B, total buildable area was about 5478 sqm [as F.A.R is 6.048 for block B].With Maximum Ground coverage, Max GC (50%), building height was 12stories (452 sqm GC) and with Minimum Ground coverage, Min GC (42%) was 15 stories (380 sqm GC). Now, buildings consuming Max GC and Min GC were grouped into three different ways and the impact of these cases on the green park have been analyzed in April at Dhaka (24degree latitude, Bangladesh) at 1.2 m (Above ground level). The simulation was done considering building height ,at plot A and C, 6 units and at plot B, 12 units (for max GC) and 15 units (for min GC), relative humidity 73% and wind speed 3.0m/s (For April). Building materials defined in ENVI-met were constant in all three cases to allow only urban form based comparison. As the built up was considered with light grey cement concrete roofs and light grey mortar finished brick walls in the three cases, U and albedo values used in simulations were as following; U value Walls [W/m²K] = 1.70,U value Roofs [W/m²K] = 2.20, Albedo of Walls = 0.30, Albedo of Roofs = 0.15. The site and road was modelled by Loamy soil (l) and asphalt road. Models for Grass (xx) of 50 cm average, dense and for Tree (dm) 20 m dense, distinct canopy layer were used for this simulation.

IMPACT OF PARK AREA

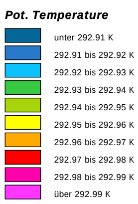
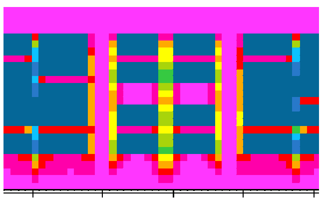
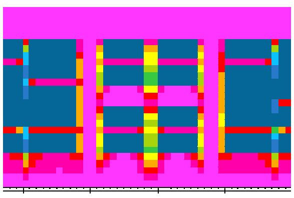
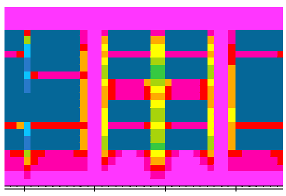
Two plots at middle of Block B, were filled up in three different ways and thus three distinct scenarios were analyzed, **as shown in Table 1,** considering a one storey building of 3m (Scenario 1), brick pavement road (Scenario 2) and a park area with grass and tresses (Scenario 3) at the plots.

Table 1. Different Site Scenarios

Scenario 01	Scenario 02	Scenario 03
		

Temperature Simulation Analysis

Table 2: Impact of Park on the microclimate (Temperature)

	Situation 01	Situation 02	Situation 03
			

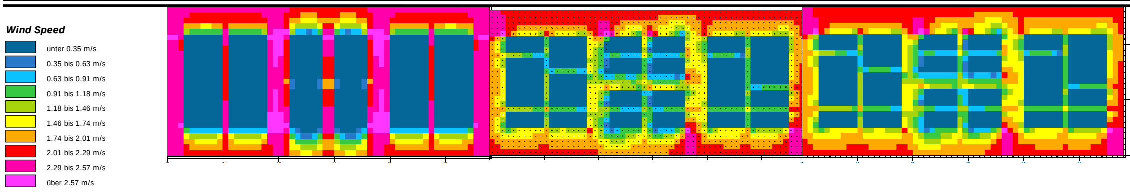
The simulation time was at 6:00am at 3m height (above street level). **Table 2** shows that the highest temperature (292.99 K or above) was found street level and the lowest temperature (292.91K or below) was at the building interior temperature. In Scenario 01 (one storied building), the temperature of the plot, at the building location, was as high (292.99 K or above) as the street level because the building roof worked as thermal mass. In situation 02 (brick pavement road), the temperature of the total area was raised as high (292.99 K or above) as the street level because of its heat storage capacity. In Situation 03(park area), the temperature is much cooler (around 292.98 K) in the park area.

So, the best result is observed at Scenario 03. As overheating is the main problem in tropical cities, these urban green spaces can play an important role to achieve the outdoor comfort in summer season by lowereing the temperature of the microclimate. In interesting finding is that, in all three cases, the temperature at the setback area was much lower (292.95 to 292.96 K) than the street surface, because of the vegetation there. So, urban open spaces can modify the urban microclimate in a very positive way in a tropical city like Dhaka.

Wind Simulation Analysis

The simulations time was at 6:00 am on 3m above street level, **as shown in Table 3.** In Scenario 01 (one storied building), very low wind speed (under 0.35 m/s) is observed at the middle plots. In Scenario 02 (brick pavement road), simulation shows a moderate (1.18-1.46 m/s) wind velocity. In Scenario 03 (park area), the simulation shows a moderate wind velocity (1.18-1.46 m/s) at the middle plots. So, urban open spaces can positively modify the urban microclimate of tropical city like Dhaka where air flow has been considered as one of the most important contributors to outdoor comfort.

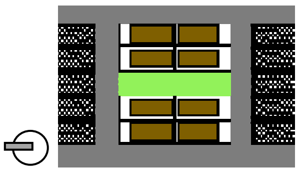
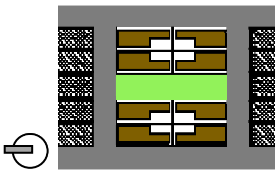
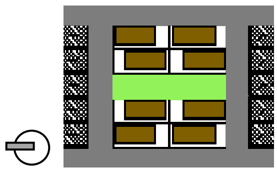
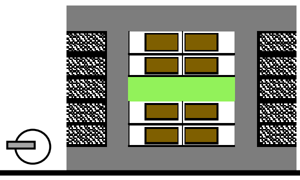
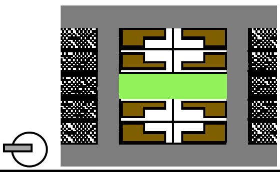
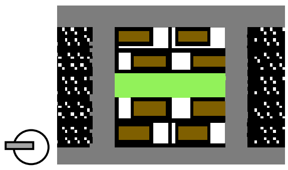
Table 3. Impact of park on the microclimate (Wind Speed)

Situation 01	Situation 02	Situation 03
		

IMPACT OF BUILDING GEOMETRY

Three distinct situations, **as shown in Table 4**, created by the grouping of the adjacent buildings of the park area, have been analyzed. Impact of the Front yard (Case Study 1), Central Courtyard (Case Study 2) and Staggering of buildings (Case Study 3) have been observed.

Table 4. Impact on park area by adjacent building geometry

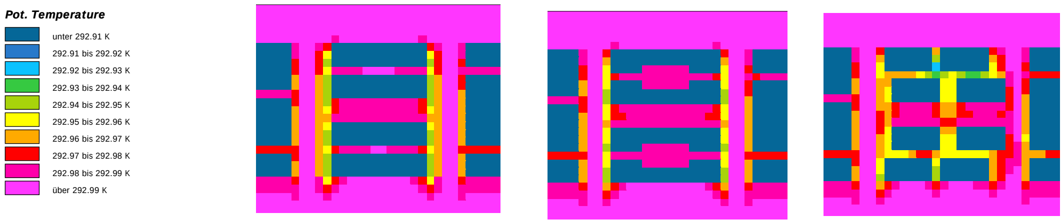
Case study 1	Case study 2	Case study 3
Max GC	Max GC	Max GC
		
Min GC	Min GC	Min GC
		

Temperature Simulation Analysis

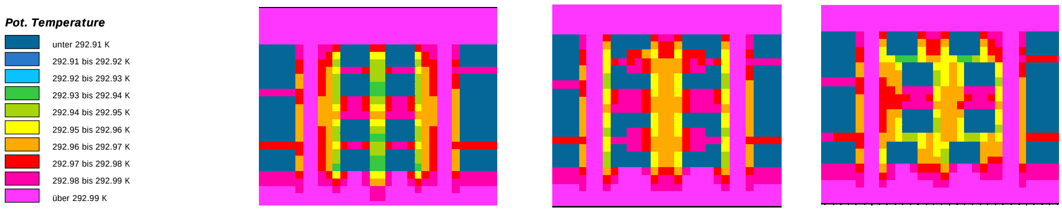
Simulations, **in Table 5**, show the result at 03:00 a.m. on 15April, 2015 at 1.2 m. In Case Study 1 (Front yard), it is observed that the cooling effect of the park was enhanced by the availability of more green open spaces when Min GC is consumed as its decrease the temperature from 292.98-292.99K (when Max GC used) to 292.95-292.96K (when Min GC used). In Case Study 2 (Central Courtyard), the park area and the central courts having temperature of about 292.98 whereas road temperature is 292.99 or more. Buildings with Min GC expressed a cooler (292.95-292.96K) microclimate in park as well as in the internal court while with Max GC, it is about 292.98-292.99K. In Case Study 3 (Staggering of buildings), a lower temperature (292.97-292.98K) is observed at the park area than at the street level.

Table 5. Impact on park area (Temperature analysis)

	Case study 1	Case study 2	Case study 3
	Max GC	Max GC	Max GC



	Min GC	Min GC	Min GC

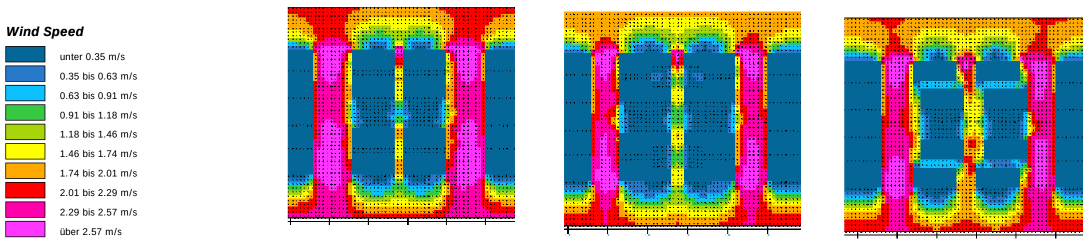


Overall temperature of the larger parts of surrounding plots showed a lower temperature (292.95-292.96K) when Min GC is used than using the Max GC. It is highly desirable for a tropical city like Dhaka. This arrangement showed the best microclimate impact on the area in the aspect of temperature control. So, building geometry and the grouping of buildings are significantly affecting the microclimatic condition of the park and the surrounding area. The Minimum Ground Coverage of the buildings shows better result in almost every arrangement at pedestrian level.

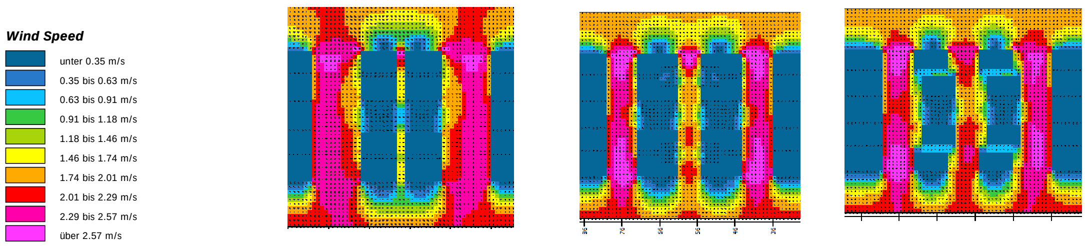
Wind Simulation Analysis

Table 6. Impact on park area (Wind Speed analysis)

	Case study 1	Case study 2	Case study 3
	Max GC	Max GC	Max GC



	Min GC	Min GC	Min GC



Simulations of **Table 6** show the result at 03:00 a.m. on 15April, 2015 at 1.2 m. In Case Study 1 (Front yard), the wind speed in the park was highly disrupted as there is no passage way between the buildings. There was insufficient air flow (under 0.35 m/s) in the area which created an uncomfortable situation at park and also hampered the building ventilation. Arrangements at Case Study 2 (Central Courtyard), severely hamperd the air flow. The park area had an air flow of about 0.35m/s-0.63 m/s, which created terrible uncomfortable situation. Though in case of Min GC, situation is a little better but still these conditions are not satisfactory. It is seen in Case Study 3 that wind speed has much increased with the staggering of buildings. With Minimum GC, the wind flow was created upto 2.01-2.29m/s at pedestrian level, which is highly needed for warm-humid tropical countries like Dhaka So, if the buildings are grouped in a staggered way to create wind passage through the urban open spaces, the increasing airflow, working as a passive tool, can provide thermal comfort in extremely humid conditions in warm-humid tropics like Dhaka.

DISCUSSION

In this study area, it is observed that buildings with minimum GC, staggered in a planned way, give better effects. So, when deciding FAR of a particular area, the existing situation has to be studied, then on the basis of that, the design decisions of "Building Geometry and Grouping" has to be generated to get the best result of an urban open space in terms of environmental benefits.

CONCLUSION

This simulation study facilitated an evaluation of the various effects created by different geometry of the adjoining buildings on the identical site. This simulation studies have been expressed in terms of a number of climate responsive urban design guidelines. It is observed that urban open spaces can modify the surrounding microclimate of the area in a very positive way in Dhaka. It has a significant cooling capacity as the green trees reduce the air temperature. It directly controls the electrical energy consumption as domestic usage demand is the highest energy consumption in Dhaka. Therefore, designing appropriate streets, buildings, urban open spaces etc is extremely impartant to reduce the urban energy consumption and develop the quality of outdoor environment (Hossain, 2010). The urban geometry of the surrounding area also has strong impact on the park. During policy making and planning session, certain guidelines should be given to control the overall microclimatic condition of an area. This study shows that building with minimum Ground Coverage performs better than that of maximum coverage both in lowering the ambient temperature and increasing wind flow. However, for buildings with elevated ground floor the result may vary. It can be said from this observation that owners should be motivated to use minimum ground coverage to create green open spaces around the buildings. This study shows, types of building grouping also create impact on the microclimate. This study illustrates an approach and methodology that could be of reference for planners and building designers.

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Energy and Resource Positive Building Design in Urban Resilience Context

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ABSTRCT

This paper presents state of art urban resilience building technologies for improving energy efficiency and saving resources, making particular reference to case studies that include a cultural building, a commercial complex, community regeneration for low income groups and system housing. Some current measures to promote green remodeling of buildings as well as developing sustainable community in Korea will be introduced with a holistic view. Through the case studies, the need for passive and low energy design in urban community resilience buildings has been identified.

INTRODUCTION

Backgroud and Purpose of Study

Environmental problems that are mainly due to the excessive use of energy and natural resources have brought about the need for a new paradigm shift. Eventually, the climate change underway today will be more than unpredictable. It has been forecast in the Stern report that GHG emissions will reduce the world's GDP by 5-20% each year. For this reason, it is urgent to realize global sustainability by improving energy efficiency and saving resources through national action plans and international collaboration. Currently, Energy Technology Perspectives 2014: 2 degree scenario predicts that the world population and economic growth with energy policy and technology adoption will reduce oil demand by 30% in 40 years. It also said that improving energy efficiency would diminish carbon emissions significantly by 50%, or more.

In Korea, the building sector currently is responsible for more than 24% of total domestic energy use, and has seen an annual increase rate of 20%. An IPCC Report estimates that in 2030, the building sector will have the highest potential for reducing CO_2 emissions. The Korean government has launched its "Low Carbon Green Growth" policy as the new growth engine for national economic development. To this end, various action plans have been made by supplying 2 million green homes with a view to developing global change mitigation as well as promoting the green economy and quality of life. A new trend of sustainable urban community regeneration has recently been promoted.

Method of Study

This is a kind of descriptive study that was conducted with a view to disseminating information and experiences on urban regeneration with particular reference to energy and resources positive building design. Representative urban regeneration projects ranging from commercial complexes to community housing have been examined in rather qualitative terms.

PROBLEM PERCEPTION

High Urbanizaion Rate

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In Korea, urbanization proceeded rapidly during the modernization and industrialization period in the 1960s. The urban population, just 2.8% in 1915, increased to 27.7% by 1960 and to 81.9% by 2010, and a level of urbanization that took Europe two centuries to achieve occurred in just 40 years. The urban population increased from 20.49 million in 1975 to 38.33 million in 2005, an increase of 17.84 million, which means an 87% increase in only 3 decades.[1)]

Urban Decline Symptoms

To counteract this drastic urbanization and industrialization the government constructed extensive new cities and industrial complexes. But beginning in 2000, the growth in the urban population became stagnant due to the low birth rate and high aging, and the economic activities of many cities were down and symptoms of a partial or total decline in social economic activities could be seen.

Figure 1 shows the declining cities in Korea. Of 144 cities and districts in the country, 55 are declining and 41 show signs of decline, which means that 67% of the cities are declining or have started declining. Of the assessment methods, the social and economic indexes presents the average population growth and reduction of change in number of enterprises in the last 5 years, and the environmental index selects the regions in which more than 50% of buildings are older than 20 years. When these 2 or more of 3 indicators are applicable, the region was evaluated as 'declined.'[2)]

The declined regions during the past high growth period are the mixed-use complex and multi-story high-rise housing areas where the regeneration projects were positively implemented. However, the original residents of the regional community were not able to afford the high housing price and increased rental. In the end, they were driven out of the community. Thus, a new paradigm shift of urban redevelopment is needed in an urban resilience context, which can be defined as 'a system to cope with physical/environmental, economic and socio-political strategies to enhance sustainable development for the human ecosystem'. The existing buildings should be refurbished to increase the region's values through facility improvement, introduce cultural spaces and procure a social safety network. Thus, it is necessary to realize sustainability by remodeling buildings and regenerating community in an urban resilience context.

BUILDING ENERGY/RESOURCES AND URBAN REMODELING POLICIES IN KOREA

Two Million Green Home Project

According to this policy, the Two Million Green Homes Project has been launched with the vision, goals and strategy as summarized in Figure 2. One aspect of the plan is to supply two million green homes, with the vision of promoting climate change mitigation, green growth and quality of life. Three major strategies are 1) Green home technologies development 2) setting up award policy 3) publicity and supply schemes.

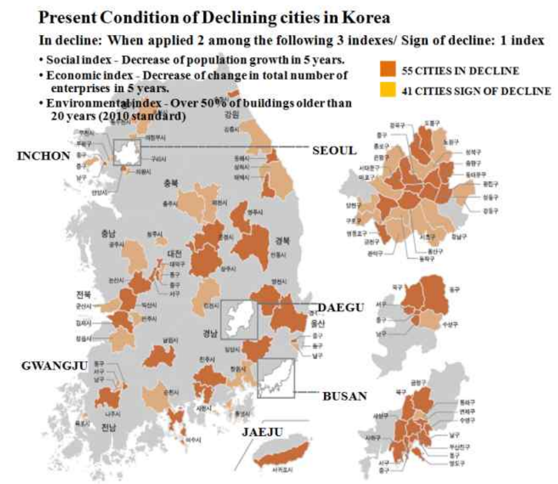

Figure 1 Present condition of declining cities in Korea

Figure 2 Concept of Two Million Green Homes

Enactment of Urban Regeneration Act

The Korean Government established the Urban Regeneration and Assistance Act in June of 2013 to effectively implement urban regeneration with the institutional and financial support of the Government. The goal of urban regeneration is to resolve the problems of the regional community by discovering regional assets such as the natural environment, culture, history and traditional heritage, on the premise that the local government and the residents comprise the main manipulator, so that the Central Government consolidates diverse assistance programs into one for effective support.

This act is composed of 3 main sectors. The first defines the organization and management for urban regeneration implemented by the central and local government and the regional community. The second defines the establishment of the urban regeneration plan. The central government proposes the basic direction for urban regeneration of the country every decade, and the local government sets up the strategic action plans for urban regeneration. The third involves the preparation of economic resources and administrative support for the regeneration.

CASE STUDIES

Cultural Building Regeneration: Rebirth of Old Government Building as a Cultural Space

The twin buildings built in the early 1960s were regenerated as a History Museum, as shown in Figure 3(left). Remodeling focuses on preserving the existing historical building by utilizing passive and low energy building design elements such as natural light, roof garden, PV etc. Eventually it has been certified to be the very best grade in terms of energy efficiency and green building performance by G-SEED(Green Standard for Energy and Environmental Design), Korean green building certification system. It is meaningful to regenerate the urban cultural space in its resilience context as a role model for urban sustainability.

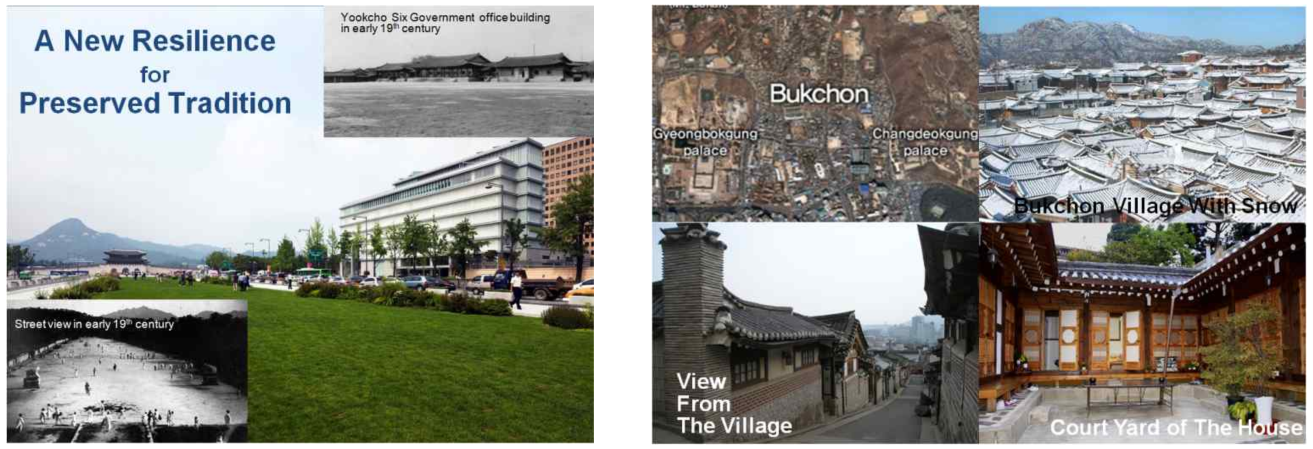

Figure 3 Urban Resilience of Tradition

Preservation of Traditional Village: 'Bukchon'

Since Bukchon's landscape was changing due to the rapid destruction of Hanoks and the construction of multi-story buildings, 'The Seoul Institute'(SI) came up with a new policy to beautify Bukchon in response to the requirements of a residents group promoting a project for the beautification of Bukchon. In the policy-making process, the SI worked with residents, experts and governmental officials. Unlike previous unilateral projects, the new policy made Hanok Registration voluntary and encouraged people to mend their houses with local government support. Since 2001, the policy has been a great success, not only in forming an attractive residential folk village but also a revitalized business area, where the residents are proud to live in Bukchon.

From an architectural point of view, it is notable that the courtyard idea of Hanok is a climate responsive low energy design in terms of inducing upward cool air movement through the inner courtyard by protecting direct solar radiation, building materials of thermal mass such as mud walls, roof tiles, and under floor heating systems, Ondol as well as the openable hanging windows for maximum ventilation during summer.(Figure 3 -right)

Mixed-Use Urban Complex Regeneration: 'Time Square'

Established in 1919 in Seoul, KyungBang is one of the oldest Korean textile companies. On this site, Kyungbang Phil department building was built in 2005. They have developed a new multiple complex by remodeling the Department building with extended complex. The complex itself aimed at: 1) providing a regeneration program for a changing society, 2) enabling a regeneration of the commercial sub-center, 3) fulfilling green building guidelines, 4) revitalizing the industrial area as an urban entertainment lifestyle center(UELC) as summarized in Figure 4.

Benefits provided by the mixed-use urban resilience complex include an increase in the floating population by 30%, revitalization of the surrounding commercial area and activation of local economic activities by upgrading regional community life for the public.

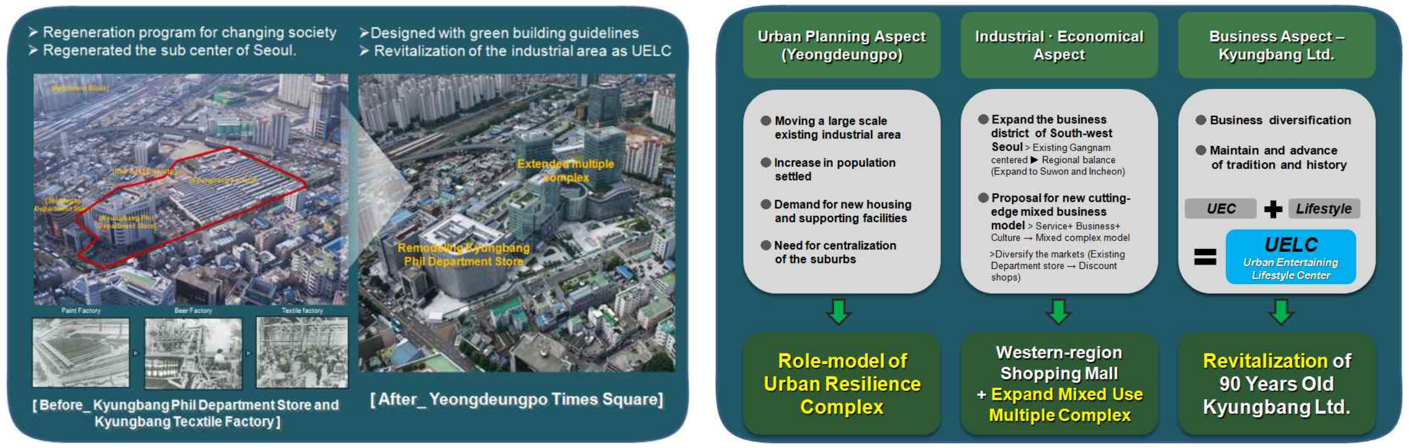

Figure 4 Evolution of New Urban Complex and Urban Resilience Goals

COMMUNITY REGENERATION FOR LOW INCOME GROUPS

Art and Culture Regeneration: 'Gamcheon Village', Busan City

Gamcheon Village in Busan, the second-largest city in Korea, is an exemplary case of urban regeneration, in which a village formed with old houses on a mountain slope was transformed into a large culture-art gallery. Gamcheon Village was formed in 1950 during the Korean War by refugees, who temporarily built their own houses on a mountain slope. The narrow and complicated alleys extend like a spiderweb through the entire village. The rebirth of this deteriorated village as a current cultural village began with the redecoration of Gamcheon village by young artists in 2009-2010. They installed 22 art works in the village and repaired broken doors, peeling walls and the general landscape of the village.

The professionals investigate and discover the assets of the village, and the artists create new art works to vitalize the village with creativity. The villagers participated actively in the villagers' conference and in the management of the village as volunteers, managers and reporters.(Figure 5) As a result of these efforts the village became known as a famous tourist attraction, and was visited by approximately 100,000 tourists in 2012.

Thus, it is significant that the example of Gamcheon village, a significantly deteriorated village that became a village of art and culture using the historical assets and the landscape of the region, is an exemplary and representative case of urban resilience.

House Repair Project with NGO: 'Nosan-dong town', Masan City [3)]

The House Repair Project in Nosan-dong is an example of household regeneration implemented as the Test-Bed of the Urban Renaissance Research Center, a Korean Urban Regeneration R&D consortium. Nosan-dong is a village/town in Masan, a southern port city in Korea, with poor residential environment and many illegal constructions, empty and deserted houses where security and crime are regional issues of concern.

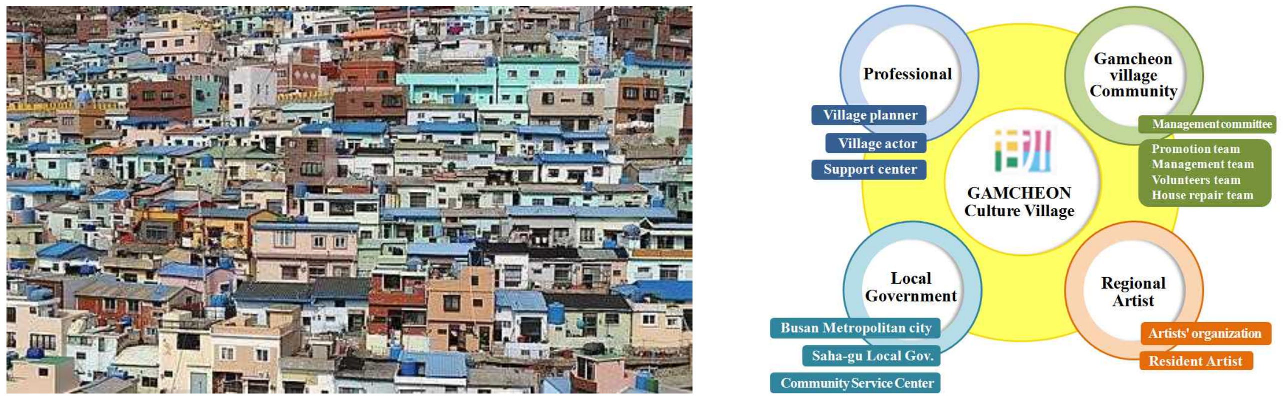

Figure 5 Panorama and Management System of Gamcheon Village

There are three factors necessary to begin the house repair project: first, organization of professional workforce to perform the project; second, selection of houses as targets of the project; third, procurement of funds for the project. First, the 'Marae Home Partner House Repair Team' was organized, to establish the professional workforce for the project. The organization of the workforce requested the voluntary participation of the Habitat for Humanity Partners. The professional and engineering workforce was organized by local veterans with experience in construction projects. The personnel expenses of the professionals and the material costs were initially covered by the Test-Bed funds.

The city provided the material costs and the residents participated voluntarily in the project. The House Repair Team will establish the regional network and register 'Marae Home Partner' as a non-profit organization to establish it as a sustainable system of house reparation and maintenance led by the residents, and thereby develop and expand the entire project. To this end, the city government is making all the possible efforts to organize the necessary assistance funds. Evenually the voluntary house repair project became a project of enhancement through energy retrofit by remodeling deteriorated houses and improving residents' quality of life by renovating the living environment. This is an exemplary urban resilience with the public participation.

A MODULAR SYSTEM HOUSING

With the changes in the construction environment, many problems are arising in the construction market. The first problem is the shortage of the skilled labours. According to the data of the Construction Workers Mutural Aid Association in 2009, Korea had a shortfall of 145,000 construction labours in 2013. The lack of skilled labours causes an increase in labour cost and total construction cost. Second, with climate change the number of construction work days has been reduced year after year. According to SI data in 2011, there were 70 rainy days in 1970 but as of 2000 this had increased to 90. This leads to extension of construction period, and increased financial costs. Third, with the strengthening of carbon emission regulation the production and disposal of construction wastes is getting more difficult than ever. This is a particularly critical factors from the perspective of energy and resource positive building design.

Advantages of System Housing

The Modular System Housing is a resources positive construction method that uses ready-made modules manufactured in a factory, which are assembled on-site, allowing a short construction period, easy removal and a high reuse rate. This method facilitates on-site installation, including the foundation work of the site, within a few weeks. This system can offer great advantages, especially in urban built-up areas.

Application of System Housing in Urban Resilience

The characteristics and merits of System Housing can be applied for urban resilience building. The "Dreaming Attic of CY" of Cheonyeon-dong, Seoul that was completed in March of 2014 is an exemplary case. This project was implemented through an agreement between the NGO "Habitat for Humanity, Seoul" and the district office. Four-story rental student housing on the public parking lot was built as a joint cooperation project, accomodating about 50 students from the countryside.

Figure 6 System Housing Constuction Process

This system housing has been designed to improve energy efficiency and building performace compared with conventional houses. To identify the high-energy performance of the competed housing in use, the annual heating and cooling load has been simulated by using IES-VE(Apache, Suncast) Ver.2014 with the input data such as number of occupants, various heat emissions, infiltration rate and the local climate data. Figure 7 shows the monthly energy consumption patterns. It has been verified that the system house energy consumption rate for heating in kWh/m^{2}yr is reduced to 21.2 from 77.0 for the conventional Korean houses, whereas the cooling in kWh/m^{2}yr is comparatively reduced less from 55.1 to 40.3.

This project is a good example of an urban resilience building model that accomplishes two goals: enhancement of land usage rate and provision of housing for lower-income groups at the community level. If this project is applied in a region with deteriorated houses and community facilities for refurbishment, it may be an excellent measure to induce public participation in improving the urban residential environment, promoting quality of life and saving energy and resources.

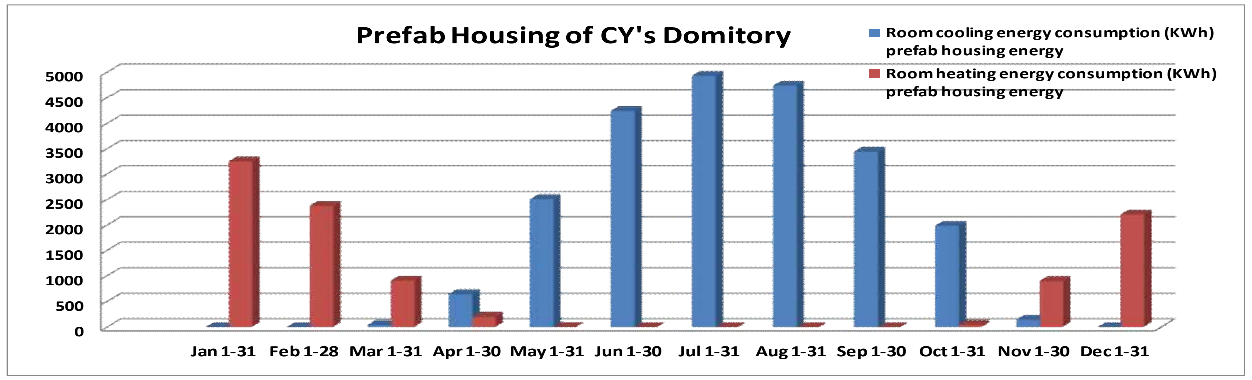

Figure 7 Simulation Profile of Mothly Energy Consumption Pattern

CONCLUSION

Through an examination of the case studies, urban resilience approach is needed to mitigate climate change for ecological protection, reducing health risks and improving quality of life. Energy and resources positive development by remodeling existing buildings and regenerating deteriorated community is greatly needed. Improvements in quality of life by providing cultural space while preserving tradition and heritage are also necessary to enhance the urban brand. Social accountability by preserving local and regional asset values, and cultural continuity are also needed to stimulate the public participation. The ways in which urban resilience building can realize sustainable development are through the integration and innovation of passive building design with sustainable materials in terms of reduce, reuse, and recycle, and the provision of high energy performance oriented community regeneration. The adoption of a new system housing is also required. However, what is more important is to enhance the public participation with administrative and financial supports from the Government, local government, voluntary NGOs, etc. Finally we must bear in mind that resilience building for realizing the global sustainability is not a fashion but for human survival on this planet

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Session 4C : User behavior, thermal comfort & energy performance

PLEA2014: Day 2, Wednesday, December 17
8:30 - 10:10, Grace - Knowledge Consortium of Gujarat

Thermal Comfort in Residential Buildings for the Elderly under Climate Changes Context

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ABSTRACT

The scientific community has seen changes in weather patterns in recent years and, according to the forecasts of the 5th IPCC Report, the Earth will suffer an increase in the average temperatures surface from 0.9°C to 1.7°C in the most optimistic projection and from 2.6°C to 4.8°C in the most pessimistic (until year 2100). This research investigates the thermal performance and comfort of residential buildings in the city of São Paulo, in the current and future climate scenarios, taking into account the projected climate change for the coming decades (following the scenarios of the IPCC Fifth Assessment Report - IPCC AR5) and the greater vulnerability of the elderly people related to environmental conditions.

For this paper, two free-running residential units were monitored, simulated using TAS (Thermal Analysis Software) and evaluated using ASHRAE 55:2013 adaptive model.

According to the adaptive criteria, one would expect that, as São Paulo climate warms, people will adapt and become accustomed to the new conditions. Nevertheless, there is a tendency of a shift to more dissatisfaction hours and, more specifically, to degree-hours dissatisfaction due to heat.

It was found that thermal mass plays an important role in thermal comfort in buildings in São Paulo current and future climate scenarios and ventilation is also a strategy in this climate and will become more important with the increasing percentage of dissatisfaction by heating hours as climate becomes warmer.

This study is part of a broader project entitled "Human biometeorology: analysis of the environmental variables (meteorological, thermal comfort and air pollution) and climate change on geriatric population of São Paulo city", involving architecture, meteorology, engineering and medicine schools at the University of Sao Paulo.

INTRODUCTION

The scientific community has seen changes in weather patterns in recent years. Although there is some uncertainty regarding projections of changes, most researchers accept their implications to increased emissions of greenhouse gases (Guan, 2012; Nobre, Reid, Veiga 2012; Oliveira, 2008) resulting from human occupation on earth, especially after the 19th century, with the industrial revolution and its consequences, and evolved to the present day. During the 20th century there was an increase in global average surface Earth temperature of approximately 0.7 °C, and the warmest years are the latest ones (Oliveira, 2008).

Brazil has recently constituted the Brazilian Panel on Climate Change (PBMC), with the goal of studies compilation on the subject related to the country. According to PBMC, Brazil's climate will be warmer in the coming decades, with gradual and variable average temperature increase in all regions between 1ºC and 6ºC by 2100, compared to that recorded at the end of the 20th century (PBMC 2013a, 2013b, 2013c).

Historically, Brazil has hydroelectricity as its main energy source. Recently, however, the participation of the thermal component is increasing (Brasil, 2012). In recent years, Brazil has reduced its emissions of greenhouse gases by reducing deforestation. Although these emissions remain representative, issues as energy and agriculture are currently the main causes in the greenhouse gases' emission. The building sector electricity consumption is increasing in Brazil and worldwide, and in 2010 it was the largest consumer of electricity in the country (PBMC, 2013c).

Energy consumption in buildings occur in every stage of its lifecycle, the highest consumption, however, occurs during the operation phase, which is mainly due to cooling and heating (UNEP 2007; Vianna, Veiga, Abranches 2009). Even though heating and cooling of residential buildings is somewhat inexpressive in Brazil, mitigation strategies should consider energy efficiency improvements in buildings, especially facing Brazilian poor people energy transition process, energy security and a gradual increase in temperatures caused by climate change in progress.

Adaptation is important for the purpose of keeping human life and health in Earth and even comfortable conditions for people. It is desirable that adaptation and mitigation have a complementary character, otherwise, or human comfort will be compromised, or there will be an increase in energy demand. Hence the importance of adapting buildings and its users to climatic parameters to which they are subjected and lower energy consumption. Adaptation may respond mainly by reducing or eliminating the risks of climate change impacts and gains relevance in the scenario that emerges, where, according to the forecasts of the 5th IPCC Report, the Earth will suffer an increase in the average temperatures surface from 0.9°C to 1.7°C in the most optimistic projection, and, from 2.6°C to 4.8°C in the most pessimistic (until year 2100) (IPCC 2014). So, taking into account energy security and human comfort issues, it's important to seek means of obtaining favorable environmental conditions with the lowest possible energy use when not by passive means, with buildings prepared to operate in free-running mode or low-energy mixed-mode.

Adaptive comfort models can be successfully adopted to evaluate comfort conditions in this situation. The use of an adaptive comfort model takes into account the tendency that people have to adapt to fluctuating environmental conditions (Nicol, Humphreys, Roaf, 2012). Adaptation can be physiological, psychological or behavioral so, a wider range of thermal comfortable conditions and a closer relationship with the external climatic environment can be obtained. Those models apply very well to naturally ventilated buildings because they tend to encompass greater thermal fluctuations, according to external variations, likewise, the users' expectations, their adaptation and satisfaction with naturally ventilated environments are different if compared with air-conditioned environment users (Cândido, De Dear, 2012; Lomas, Giridharan, 2012). Therefore, different recommendations are proposed for air-conditioned and free-running buildings, because the thermal tolerance response has been shown to be different for building users under these two thermal conditioning alternatives. Following this approach, the user is no longer seen as passive to the surrounding environment, but as the controller of it, by the operation of simple mechanisms such as opening or closing a window, and, so, been able to increase their satisfaction.

There are two international standards which propose an adaptive model: the American ASHRAE 55 (2013) and the European EN 15251 (2007). The last one was made through studies in European countries, while the the first was based in ASHRAE RP-884 project wich took recordings in many countries around the world (De Dear, Brager, 1998). Diferently of EN 15251, which includes 3 categories (I, II and III) and indicates the adoption of the most restrictive category for elderly occupants, ASHRAE standard presents only 2 ranges (80% or 90% of satisfied people) and no specific indication for the elderly.

SÃO PAULO: CURRENT AND FUTURE CLIMATE SCENARIOS

Located in southeastern Brazil (23,5ºS; 46,6ºW), São Paulo is the biggest city and the financial center in the country. This is the main city of the biggest Brazilian metropolitan region and one of the largest conglomerates in the world, the Metropolitan Region of São Paulo (MRSP). The climate is subtropical (Cfa according to Köppen classification) with mild temperatures: warm humid summers; cool and drier winters. The climatological normals recorded by the National Institute of Meteorology (INMET, 1992) from 1961 to 1990 indicate annual average temperatures of 19.3°C and average minimum and maximum temperatures ranging from 15.5°C to 24.9°C.

Precipitation shows periods with more and less rainfall amounts in the MRSP, represented by rainy months of december, january, february and march and the dry months of june, july and august. the distribution of rainfall throughout the year is determined by the influence of weather systems such as cold fronts, South Atlantic Convergence Zone (SACZ), squall lines and breeze. The rainy months are also the hottest, averaging around 21.0ºC when February is the warmest. The driest period is also the coldest, and July is the coldest month. However during the year are recorded extreme temperatures that reach near 0ºC in Winter and above 30ºC values in Summer , due to different meteorological phenomena such as synoptic scales (air masses , frontal systems , etc.), mesoscale (as the sea breeze) and micro-scale (local effect as the urban heat island) . The heterogeneity of the urban area of the MRSP causes frequent situations in which they routinely are differences between more and less urbanized regions, with higher and lower, respectively temperatures.

To mention the future predicted climate, projections for the region indicate increase in the number of hot days, reduction in the number of cold days, increase in the number of warm nights and decrease in the number of cold nights (Nobre *et al*., 2010).

Future climate simulations were carried out by the Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG-USP) using two meteorological models: the Regional Climate Model system - RegCM4 supplied by the Geophysical Fluid Dynamics Laboratory (GFDL) global model. They indicate a future mischaracterization of the MRSP climate. As a consequence, a regular year which used to have separate seasons will display basically two periods: a warm season (september to april) and a mild season (may to august). This was also demonstrated by Marengo (2006) through simulations forced by the IPCC AR4 A2 and B2 scenarios, indicating a positive temperature anomaly that changes the climate of southeastern Brazil toward a tropical pattern.

These changes are even more noticeable from the perspective of the seasonal trend index. It presents an increase of hot days in all four seasons, particularly spring, summer and autumn. It means that regular years in the future will have a larger number of warm days (in which AT[1]≥22.6°C) corroborating Marengo (2006) and Nobre *et al.* (2010). This increase in AT is also observed during winter, with a weaker increase in hot days and a significant reduction in cold days.”

These changes also indicate the possibility that events that do not usually happen in the MRSP start to occur, such as heat waves (Rafael Batista, IAG USP meteorologist, personal communication, March 28, 2014).

DATA COLLECTION

Residential units

[1] AT is the the apparent temperature, according to Steadman (1994). It follows the principle of an equivalent temperature, which is the temperature at a certain level of moisture that produces the same amount of discomfort experienced under the actual conditions of temperature and humidity.

For this study, two residential units were monitored, simulated by computer software and the results were evaluated. Households are elderly people assisted by the Public Hospital of the Medical School of the University of São Paulo, who kindly volunteered to participate in this research.

The first one, Cerqueira César housing unit, is a second floor apartment, which is part of a 10-story building, four apartments per floor, located in a dense central urban area of São Paulo city. It is 62m², inhabited by a 3 persons family. The second, Rio Pequeno house, is a one-story house in a densely occupied but low rise and mixed-use region of the city. This is a 65,5m² house inhabited by a 4 persons family. Both residences are presented in Figure 1.

The dwellings were built over 40 years ago and are made of traditional Brazilian building materials, with vertical sealing build of clear painting mortar coated clay brick which heat transfer coefficient (U value) is around 2 W/m^2°C. The ceiling height is 2.7m in both cases. Cerqueira César apartment is concrete ceiling and Rio Pequeno is solid slab and fiber cement tiles roof. They are both free-running buildings and have operable windows. The bedrooms' windows are composed by glass and venetian metal or timber sliding sheets.

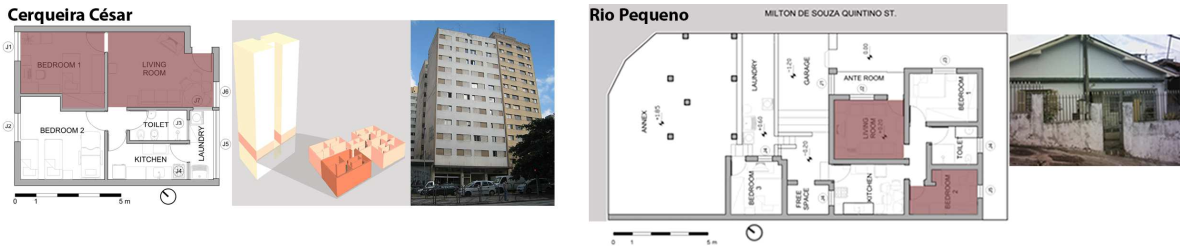

Figure 1. Cerqueira César and Rio Pequeno housing units.

Empirical data

For the empirical data, recordings of environmental variables were carried out using comfortmeters during the cooler and warmer period, respectively in april and december 2013, within the living room and the bedroom. The measured variables were air temperature, relative humidity, globe temperature and air velocity. For the external database, meteorological data was obtained from the IAG-USP meteorological station[2]. Mean recorded temperatures are shown in Table 1.

Table 1. Measured mean temperatures data. Comparison between external data and São Paulo average climate reveals the representativeness of the measurement periods as cold (April) and warm (December) days.

		April			December			São Paulo Climate**		
		External data*	Living room	Bed room	External data*	Living room	Bed room	Colder months average	Warmer months average	Year average
Mean temperature	Cerqueira César	17,4	21,9	23,0	23,2	25,7	26,8	16,5	22,1	19,3
	Rio Pequeno		24,2	23,3		29,1	28,3			
Mean of maximum temperatures	Cerqueira César	21,7	22,8	24,2	28,8	27,4	28,7	22,3	27,5	24,9
	Rio Pequeno		25,0	24,1		32,0	29,7			
Mean of minimum temperatures	Cerqueira César	13,8	21,1	22,1	19,8	24,1	24,9	12,3	17,8	15,5
	Rio Pequeno		23,2	22,6		27,5	27,1			

*External data from IAG Meteorological Station.

**According to climate normals: period 1961-1990

The objective of the monitoring was to calibrate the computational model for local climate

[2] Located at 23.6512°S and 46,6224°W, 799,2 m above sea level, in a green park in southern São Paulo city.

conditions in both residential units. As free-running buildings, temperatures and humidity variability is closely related to external conditions, but the buildings' envelope generate an internal microclimate: due to their average thermal mass, they alleviate the great external variability and retain part of the thermal load for a few hours. So, the mean internal temperatures is always higher than the external and there is diurnal and annual variability accompanying the seasonality of the external environment, as shown in Figure 2.

Although they are located in different urban contexts, possible differences in microclimate caused by diverse urban fabric were not evaluated in this study.

THERMAL COMPUTATIONAL SIMULATIONS

Model calibration

The virtual models were built and the thermal simulations were performed based in geometry and building components previously obtained. The computational model adopted is TAS (Thermal Analysis Software). For this purpose, IAG-USP Meteorological Station 2013 data were adopted, including air temperature, relative humidity, wind velocity and direction. Besides these variables, solar radiation (global and diffuse) and cloud cover data were added from another database.

After thermal simulation air temperature, mean radiant temperature and relative humidity were compared with measured data for the same period, aiming to calibrate the model (see Figure 2).

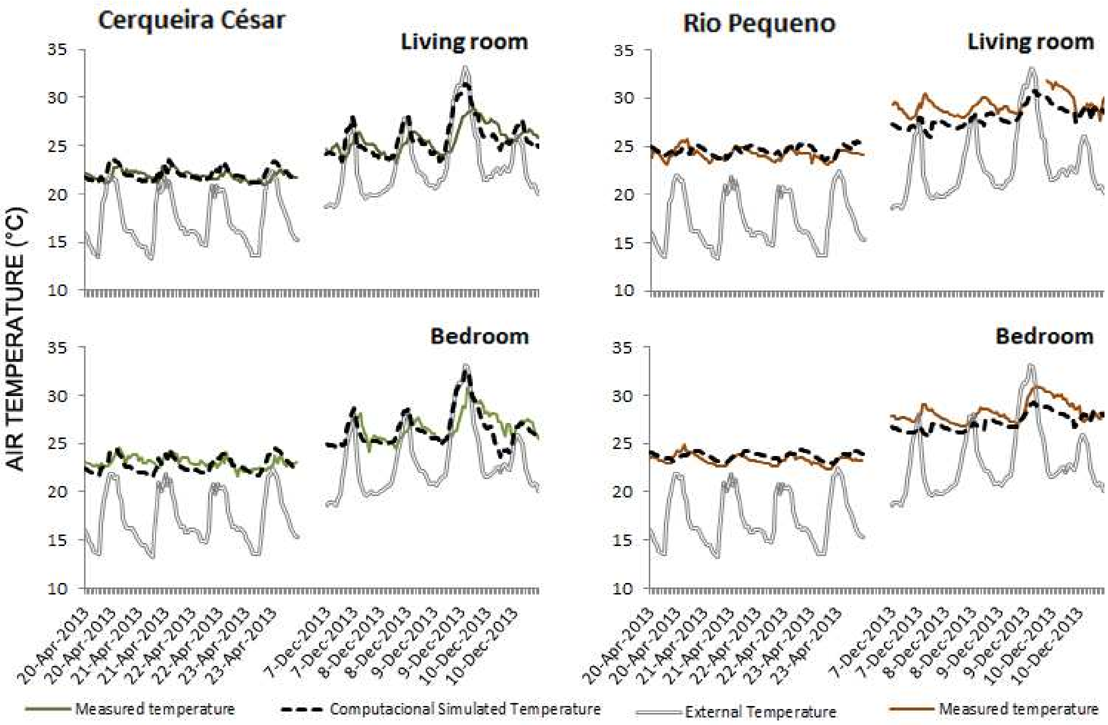

Figure 2. Air temperature recorded and simulated comparison as one of the thermal variables used for model calibration.

Computational simulations

Simulations were carried out both in current and future climate scenarios. Therefore, four weather files were employed representing present (1975-2005), near future (2015-2044), intermediate future (2045-2074) and far future (2076-2096) scenarios. Temperature and relative humidity data representative of each period were obtained from IAG-USP simulations, based on the RCP 8.5 scenario from IPCC AR5, the most carbon intensive scenario. The weather data were simulated using two models: RegCM4 regional model and MPI (Max-Planck Institute for Meteorology) global model.

Comfort condition evaluation

ASHRAE 55(2013) standard adaptive model was adopted to evaluate comfort results in the building models. As this study is dealing with residences for the elderly, the most restrictive range was chosen: 90% satisfied users[3].

The index was applied in simulated thermal results for all years represented by the four climatic pictured situations: present, near future, intermediate future and far future.

Considering the current trend of using more lightweight materials in construction due to cost reduction, an alternative version of the models was parameterized appling more lightweight materials than the current building components. The changes in building components were:

. use of 12cm concrete walls (U value ~ 4,2 W/m^2°C) to replace the 24cm mortar coated clay brick (U value ~ 2 W/m2°C) in both models;

. use of pvc liner (U value ~ 4 W/m2°C) to replace the precast slab (U value ~ 2,75 W/m2°C) ceiling in the Rio Pequeno house (not applied to Cerqueira César apartment).

In every case, the windows are operable and they are opened as internal temperature increases.

One may notice a progressive reduction in the percentage of “disfaction by cold” hours and an increase in “dissatisfaction by heating” hours along with the climate scenarios progression and a slight reduction in percentage of hours in comfort along them in both current residences’ condition and in the hypothetical situation (more lightweight materials).

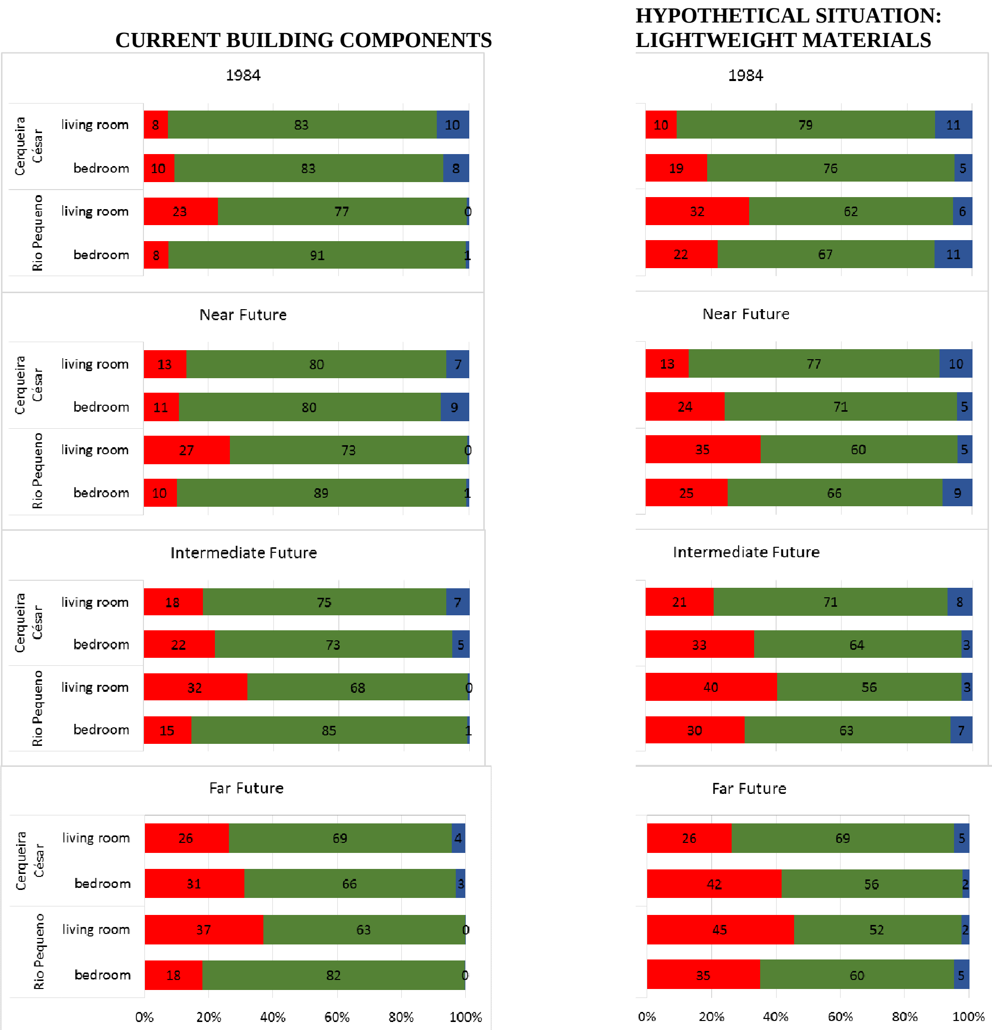

Figure 3. Time percentage with internal temperatures within ASHRAE 55 (2010) thermal comfort for 90% satisfied people for both residences, using the current building components and for the hypothetical situation with more lightweight materials.

[3] The ASHRAE55 (2013) model was adopted because of its varied database location. The option for the most restrictive range of satisfied people was adopted by analogy with the European standard, wich indicates adoption of its most restrictive category for elderly occupants.

Figure 4. Degree-hours in discomfort for each evaluated room in the three different climate scenarios. Positive values indicate degree-hours of discomfort by heat and negative values, by cold.

The comparison between the two models proposed (current building components and more lightweight materials) presents a better condition for comfort sensation in the first case, in which the dwellings have greater thermal inertia, in every climate scenario, both for warm and cold condition. The observation of degree-hours of discomfort clarifies the discomfort condition due to climate warming progression: the discomfort becomes more prominent as the climate warms.

CONCLUSION

According to the adaptive criteria, one would expect that, as São Paulo climate warms, people will adapt and become accustomed to the new conditions. Nevertheless, there is a tendency of a shift to more dissatisfaction hours and, specially, to degree-hours dissatisfaction due to heat.

Thermal mass plays an important role in thermal comfort in buildings in São Paulo current and future climate. Ventilation is also an important strategy in this climate and will become more important with the increasing percentage of dissatisfaction by heating hours as climate becomes warmer.

It is important to notice that the simulated climate change scenarios, simulated by IAG-USP, do not include the urban heat island effects, so, climate change temperatures probably will be higher than the ones considered in this study.

Finally, it is emphasized the difficulty to obtain climate data, especially hourly data covering all variables used for thermal simulation of buildings, both measured and simulated.

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Shifting the norm - towards effective mixed mode buildings

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ABSTRACT

A mixed mode of operation, where supplementary air-conditioning is used only when indoor conditions ride outside the acceptable comfort range, can reduce the carbon footprint of the building. The paper uses four post occupancy studies of mixed mode building, two each from Australia and India to investigate successes and pitfalls. All four buildings succeeded in integrating a mixed mode of operation at a tectonic level, but feedback from the occupants was varied. The study showed that occupants can be forgiving of minor discomforts when other positive attributes are included, but the risk to performance is intensified when occupants perceive very little adaptive opportunity or problems are not rectified quickly. It identified a tolerance of higher temperatures in the Indian mixed mode buildings in contrast to the Australian experience where narrow limits serve to further entrench an expectation for air-conditioning and generate an energy impost. The findings of this paper question year round air-conditioning and challenge designers to rethink spatial and environmental opportunities in the context of the changing workplace when shifting the norm towards effective mixed mode buildings

INTRODUCTION

As workplaces in developing countries such as India are designed to the standards of contemporary western workplaces, year round air-conditioning (AC) operated within a narrow temperature range is fast becoming entrenched as the primary means for environmental control. Coupled with the rapid increase in office floor space, this trend is expected to fuel India's soaring demand for electricity unless serious measures are introduced to counter the energy-intensive approach (Thomas et al, 2010). On the other hand, studies have shown that a mixed mode of operation, where supplementary AC is used only when indoor conditions ride outside the acceptable comfort range, has the potential to drastically reduce the energy and carbon footprint of the building whilst satisfying comfort requirements (Brager, 2006; Leaman & Bordass 2001). Despite its benefits to both developed and developing contexts, a mixed mode of operation remains poorly understood and the uptake remains low. Furthermore its design and implementation is not without challenges. Drawing on feedback from post occupancy studies of mixed mode buildings in Australia and India, the paper will discuss why some buildings work well and others don't and what lessons can be learnt towards their effective implementation.

STUDY APPROACH

A post occupancy evaluation methodology noted for its ability to provide vital feedback on building performance and occupant satisfaction (Bordass et al, 2001, Vischer, 2007) is used to analyse four mixed mode buildings –two each in Australia and India-and all recognized examples of sustainable architecture. The Australian buildings (A-AUS, Sydney; and B-AUS, Melbourne) are located in a temperature climate characterized by warm/hot summer and cool winters, while the Indian buildings (C-

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IND, Delhi and D-IND, Gurgaon) are located in the relatively more challenging composite climate of the National Capital Region characterized by long hot summers, a humid monsoon, and dry cool winters.

The study approach includes a review of project information, site visits, interviews with key stakeholders (owner/developer, design team, and building manager) and a survey of building occupants to develop a context specific rich narrative of building performance. The Building Use Studies (BUS) Workplace Questionnaire Survey (paper based) was used to elicit the occupants' experience during their time in the building. Used in over 500 buildings worldwide including Australia and India, the survey covers 63 variables ranging from environmental comfort, user control, and design to perceived productivity and health. The survey was administered after at least one year of occupancy in three of the study buildings and nine months in C-IND. This ensured that occupants had experienced the full range of seasonal variation in the building, while overcoming any "Hawthorne effect" (Landsberger, 1958) associated with the short-term improvements arising from the novelty of introduced changes.

This paper also draws upon data collected as part of a thermal comfort field (TCS) study (after deDear & Brager, 1998) towards the development of the India Model for Adaptive Comfort (IMAC) (Manu et al, 2014 forthcoming) with particular focus on the occupants' response to thermal sensation, acceptability and office comfort as experienced "right here, right now" in buildings C-IND and D-IND.

The pertinent outcomes for each building are discussed in relation to design approach, building attributes and environmental control strategies below. Broader lessons from these studies as well as other implications for mixed mode buildings drawn from the literature and the author's experience of other buildings in both countries/contexts are discussed later in the paper. Sectional drawings of the four study buildings are provided in Figure 1, and relevant BUS and TCS data in Tables 1 and 2 respectively.

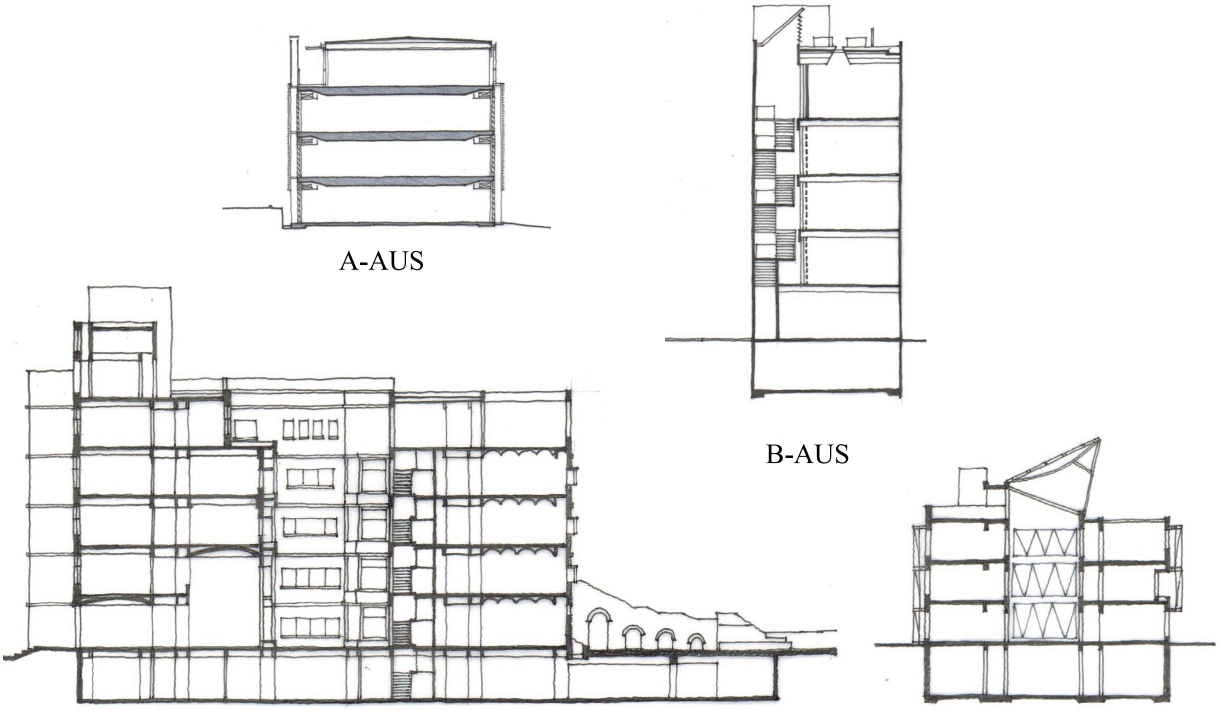
POE STUDIES FOR FOUR MIXED MODE BUILDINGS

Building A-AUS, Sydney

Completed in 2001, this 2000m^2 owner occupied office building accommodates 120 employees. The building has been credited (Thomas & Hall, 2004) as an early example where client commitment to sustainable design was matched by a development process in which tangible environmental criteria considered at project inception enabled the building to meet its energy targets. The building design is driven by a passive stack ventilation system that serves three of its four floors. Air is drawn across the narrow 15m floor plate through louvers on the south façade and exhausted through the solar chimneys on the north. A high level of tectonic integration is evident - an external screen of corten steel louvers provides sun-shading and security to the high performance glass facades and its openings, while the solar chimneys are detailed within the space between the twin blade columns. Supplementary AC via a variable refrigerant (VRV) system is ducted along the perimeter to maximize exposure of thermal mass in the concrete ceiling. The switch between passive (stack ventilation) and AC modes is controlled via a building management system (BMS). The acceptable temperature range was set to 19-25°C with an expectation of a greater tolerance in a mixed mode building compared typical AC workplaces.

Although the building achieved a strong 4.5 star ABGR energy performance[1], the occupant feedback in the BUS survey (Table 1) was disappointing. Occupant perception of excessively hot temperatures and the lack of adequate airflow resulted poor scores for temperature and air. This was traced to an erratic temperature and ventilation control system driving the louvers and excessive overheating on the upper floor (which was not linked to solar stack) compounded by a low perception of control when things were not working. Following complaints the set-points were narrowed to 20-24°C. Occupants also raised noise concerns which were caused in part by a lack of alternate break out spaces in an open plan environment and aggravated by the highly reflective surfaces of the exposed concrete ceilings. This exacerbated occupants' dissatisfaction and served to drive down scores for overall comfort, design, and perceived productivity and health. The study highlights that buildings that perform poorly from the occupants' perspective have a negative impact on their ability to do work

[1] ABGR is the former name for National Australian Building Environmental Rating Scheme (NABERS) energy rating system in Australia. In 2002, no building as large as Building A-AUS had realized the top 5 star rating achievable at the time.



A-AUS

B-AUS

C-IND

D—IND

Figure 1 Cross sectional view of study buildings

Building B-AUS, Melbourne

Building B-AUS (Thomas and Vandenberg, 2007) was fully refurbished between 2004 and 2005 to provide 1200m^2 of office accommodation in a block constrained by its 10m x 55m footprint and glazed openings only on its shorter edges. The key architectural invention was to remodel the existing stair (alongside one of the 55m long party walls) into a light well and thermal stack for passive ventilation through the floor plate, changing the dynamics away from the lifts and constant AC. The office spaces are designed to operate in a 19-25°C temperature range during occupied hours, with a BMS controlling the switch over to the fan coil units in the ceiling, a night purge strategy to pre-cool the thermal mass inherent in the exposed concrete ceilings.

As seen in Table 1, the building recorded a level of high user satisfaction, and mean scores of survey responses for temperature, air and overall comfort are significantly better than both scale midpoints and BUS benchmarks. The high ratings for environmental aspects are influenced by the building management strategy whereby temperature, humidity, daylight and lighting levels, air quality and occupation are all monitored by the BMS, and appropriate responses are initiated by the building manager if things go wrong. This has ensured that early problems such as incorrect set-points in winter and a night-purge system which was operating regardless of outside temperature, were quickly rectified. Consequently, even though users perceived a low level of personal control over their environment, this had little impact on their ratings for overall comfort. The occupants also rated the building highly for its design, facilities, formal and informal meeting spaces, space utilization and perceived health and productivity. The building achieved a 6 star Green Star Office Design rating and its low energy design has consistently returned a 5 Star NABERS Energy rating since completion.

Building C-IND, New Delhi, India

This 3100m^2 building is head office to a non-governmental organization and was designed in close consultation with the owner occupant client group to prioritise sustainability. C-IND was awarded a LEED platinum rating and emphasizes low embodied energy materials, local construction methods and passive design to minimize operational energy. The design (Lall, 2010) integrates narrow office floor plates and a series of unconditioned spaces around a sheltered courtyard. Exposed vaulted ferro-cement ceilings and insulated fly ash cement block walls serve to stabilize internal temperatures. The structural system also integrates the air distribution channels - conditioned air is delivered at floor level through the U-shaped internal columns and returned through the hollow spaces between the vaulted ceiling elements. A range of fenestration treatments provide the occupants with a high degree of control over sun, daylight and natural ventilation. Occupants also have control over electric lighting and ceiling fans. In the original design, the building was intended to operate in a 100% passive mode from the end of September to early March, with the understanding that winter mornings would be colder than deemed comfortable. The "active-cooling" of this mixed mode building was originally designed as an innovative 2 stage hybrid Air conditioning system with evaporative cooling as the primary mode over the dry summer (March to June), and a second stage of cooling using mechanical refrigeration for the humid months (July and August). This was not installed due to unforeseen logistics and funding barriers. The client organisation moved into the building in late 2011 and while the upper two floors were untenanted, the building remained without AC over the first summer. Subsequently a conventional AC system, capable of providing heating and cooling to Levels 1 and 2, was installed at the start of the monsoon season.

Table 1. Summary of BUS Survey Results for Study Buildings

	Building A-AUS Sydney n=59, N=120			**Building B-AUS Melbourne** n=26, N=30			**Building C-IND New Delhi** n=44, N=75			**Building D-IND Gurgaon** n=58, N=90		
Benchmark dataset used for comparison	Australian benchmark 2003			Australian benchmark 2006			International benchmark 2013			International benchmark 2013		
Variable	**Score**	**% dissat**	**Result**	**Score**	**% dissat**	**Result**	**Score**	**% dissat**	**Result**	**Score**	**% dissat**	**Result**
Air In Summer	3.1	66%	Worse	5.6	11%	Better	3.9	39%	No diff	5.4	7%	Better
Air In Winter	3.4	60%	Worse	4.4	40%	No diff	4.8	16%	No diff	5.7	5%	Better
Air In Monsoon							4.7	12%		5.3	0%	
Temperature In Summer	3.2	58%	Worse	5.4	10%	Better	3.1	64%	Worse	5.4	12%	Better
Temperature In Winter	3.4	55%	Worse	4.4	31%	Better	4.3	15%	No diff	6.0	1%	Better
Temperature In Monsoon							4.8	20%		5.4	4%	
Lighting	5.1	14%	No diff	6.0	8%	Better	6.0	0%	Better	6.2	0%	Better
Noise	3.4	60%	Worse	5.1	15%	Better	5.2	11%	Better	5.6	9%	Better
Comfort Overall	3.6	46%	Worse	5.7	12%	Better	5.1	7%	No diff	5.6	1%	Better
Productivity (Perceived) %	-13.5	46%	Worse	6.0	4%	Better	2.8	36%	No diff	11.7	14%	Better
Health (Perceived)	3.1	56%	Worse	4.7	4%	Better	4.7	6%	Better	5.1	2%	Better
Design	3.7	46%	Worse	6.3	4%	Better	5.8	2%	Better	6.4	0%	Better
Do Facilities Meet Needs?	4.2	37%	No diff	5.9	8%	Better	5.5	4%	Better	6.0	1%	Better
Control Over Cooling	1.8	90%	Worse	2.4	73%	No diff	2.6	65%	Worse	2.7	62%	No diff
Control Over Heating	1.8	91%	Worse	2.4	73%	No diff	2.5	67%	Worse	2.5	66%	Worse
Control Over Lighting	1.7	90%	Worse	4.0	42%	No diff	5.8	5%	Better	4.4	31%	Better
Control Over Noise	1.9	89%	Worse	2.6	65%	No diff	3.9	33%	No diff	3.4	47%	No diff
Control Over Ventilation	2.0	86%	Worse	2.0	81%	Worse	4.9	20%	Better	3.3	54%	No diff
Forgiveness	0.99		**No change**	1.10		**Forgiving**	1.10		**Forgiving**	0.97		**No change**

n = number of respondents; N = number of occupants.
Each variable above is rated on a 7-point A type scale (1 is worst, 7 is best) with the exception of perceived productivity rated on a 9-point scale.
% dissat refers to percentage of dissatisfied respondents - based on those rating the variable as 1, 2 or 3 on the 7-point A type scale.
Result indicates if the mean building score is significantly Better or Worse or No different to the mean of the corresponding benchmark dataset.
Forgiveness is a measure of tolerance and is calculated as Comfort Score/Average of scores for Temperature, Air, Noise, and Lighting
If this ratio is greater than 1, it means occupants are forgiving.

The results of the BUS survey administered in August 2012 indicate user satisfaction is better or no different to both scale midpoints and BUS benchmarks for most variables (Table 1). Unsurprisingly, the absence of active cooling in summer yielded the worst results for overall temperature conditions in summer with 58% dissatisfied and 48 % rating the building as too hot. While overall conditions were rated no different to the benchmark for winter, 49% of the occupants felt the conditions were on the colder side of neutral. The TCS surveys (Table 2) reinforce this experience for summer (avg_ash=+1.7, 65% rating conditions as unacceptable) and winter (avg_ash=-1.0, 53% rating conditions as unacceptable) in weeks when the 7 day running mean (out7day_ta) was 40.6°C and 18.4°C respectively. An interesting finding is that occupants at C-IND are more "forgiving" in that their overall (BUS) and seasonal (TCS) ratings for office comfort are higher than would have been predicted by scores for temperature, lighting, air and noise. This can explained by a number of positive features in the overall design, and is substantiated by the high occupant satisfaction with lighting, daylight, noise, control over lighting and ventilation, design, work facilities and perceived health.

While a full energy monitoring of C-IND was not undertaken, the TCS survey measurements provide a glimpse of the moderating influence of the building envelope in extreme summer. With no supplementary cooling in play, the spaces maintain indoor operative temperatures (avg_top= 36.2°C) around 7 degrees less than T_{max} of 43°C and at par with T_{min} of 36°C. Likewise in the absence of supplementary heating in winter, the building just manages to maintain operative temperatures (all measured between 9:30am &12noon) at 17.9°C close to the 7 day running mean (out7day_ta) of 18.4°C.

Table 2. Selected TCS Survey Results for Indian Study Buildings

			Field Measurements and derived parameters								*Field Survey*			*Calculated Indices*		
	Survey month/ year	Num -ber of votes	Mean indoor air temper-ature (°C) **avg_ta**	Mean indoor radiant temper-ature (°C) **avg_tr**	Mean indoor relative humid-ity (%) **avg_rh**	Mean indoor air-speed (m/s) **avg_ vel_a**	Mean metabo lic activity (met) **avg_ met**	Mean insula-tion chair + clothing (clo) **avg_ insul**	7 day outdoor running mean (°C) **out7 day_ta**	Mean indoor opera-tive temper-ature (°C) **avg_top**	Mean ASHRAE thermal sensatio n vote (+3 hot; -3 cold) **avg_ash**	Thermal accepta bility % rating unacc-eptable **tsa_ dissat%**	Mean Office Comfort Score (1; 7) **avg_ comf**	PMV (+3 hot; -3 cold) **avg_ pmv**	PPD (%) **avg_ ppd**	*Indicative results for Neutral Operative Temper-ature* ***T_{op}neut (LR)***
BUILDING C-IND																
Summer	Jun 12	66	36.2	36.3	43%	0.5	1.2	0.8	40.6	36.2	**1.7**	65%	4.3	**3.0**	100%	
Monsoon	Aug 12	45	26.9	27.3	62%	0.2	1.3	0.8	32.3	27.1	**-0.1**	3%	5.6	**1.1**	39%	*28.2*
Winter	Dec 12	52	17.9	17.7	52%	0.1	1.2	2.2	18.4	17.8	**-1.0**	53%	5.0	**0.5**	12%	
BUILDING D-IND																
Summer	Jun 12	55	26.1	26.4	43%	0.2	1.2	0.8	39.9	26.2	**-0.1**	13%	6.4	**0.6**	19%	*27.4*
Monsoon	Aug 12	62	25.2	25.6	60%	0.2	1.2	0.8	31.3	25.4	**-0.1**	5%	6.1	**0.6**	20%	*26.1*
Winter	Feb 12	64	24.1	23.6	38%	0.1	1.3	1.5	15.7	23.9	**0.1**	5%	6.0	**0.9**	24%	*22.4*

Data Source: IMAC Study (Manu et al, 2014 forthcoming).

- Office occupants' response to thermal sensation *avg_ash* is recorded on a seven point ASHRAE thermal sensation scale (+3 hot; -3 cold)
- *tsa_dissat%* is the percentage of occupants rating 'unacceptable' for thermal acceptability on a binary scale (1 = unacceptable, 2 = acceptable)
- Office comfort (right here, right now) is rated on a 7-point A type scale (1 = uncomfortable to 7 = comfortable)
- The 7 day outdoor running mean *out7day_ta* is derived from weather station data.
- The average Predicted Mean Vote *avg_pmv* and predicted percent dissatisfied *avg_ppd* for each cohort are calculated from field measurements
- Neutral Operative Temperature *T_{op}neut (LR)* is derived by Linear Regression on Observed Sensation controlling for extrapolation outside observed range

Building D-IND, Gurgaon, India

Located approximately 35km from New Delhi, D-IND is designed to house multiple tenants, with a research institution as its primary owner occupant. The LEED Platinum rated building is designed to reduce energy demand by facilitating natural ventilation and glare free daylight and minimizing unwanted heat gains through narrow floor plates, sheltered courtyards, appropriate fenestration and insulation to the building envelope. Passive air flow through operable windows is aided by the stack effect in the light well. AC is provided when conditions are not conducive for natural ventilation using a displacement ventilation strategy whereby air is delivered at floor level and returned at ceiling level. Ducting is integrated with the internal structure and partitioning system to ensure air flow paths are not impeded and concrete ceilings remain exposed to the internal space. The AC system is only operated in the periods between March to September, and December to January. Although it is linked to a BMS, a highly experienced building manager onsite plays a proactive role in moderating the set points and hours of operation based on the use of ceiling fans (not accounted for by the BMS), time of day and season.

The BUS survey results show a high level of user satisfaction across all summary variables comfort variables (temperature air noise and lighting) as well as design, perceived productivity and health (Table 1) and bear out the efforts towards integrated design and occupant comfort. All TCS survey campaigns at D-IND occurred when the AC system was typically in operation. The results indicate a strong level of acceptance of thermal conditions (avg_ash in the range of -0.1 to +0.1, Table 2), with only 5-13% rating conditions as unacceptable. This satisfaction with overall temperature conditions is corroborated in the BUS study scores for temperature and air across all 3 seasons. Although perceived control over ventilation is rated no different to the BUS benchmark, occupants made full use of ceiling fans. For example, over two thirds of occupants had their ceiling fans switched on concurrently with AC at the time of the TCS summer survey. However on site interviews indicated occupants were less enthusiastic about opening windows to their office even in the mild season, citing dust and noise.

OPPORTUNITIES AND BARRIERS TO MIXED MODE BUILDINGS

A successful mixed mode building needs to maximize occupant comfort and mimimise energy use across both its modes of operation. This in turn is affected by inter-related considerations including user expectations for comfort, the manner in which that comfort is provided for under each mode, the extent of passive operation achieved, control strategies for change-over and occupant interaction, and the potential of the building fabric and systems to moderate comfort and energy in use.

A climate responsive approach to building design supported by committed clients, and skilled design team is a critical first step to ensuring **low energy outcomes**. This aspect is the well understood in the study buildings. Each goes beyond basic application of passive design principles to achieve a tectonic integration of building elements where each 'does more than one thing'. In a market where passive technologies are viewed as an add-on cost, strategies such as the merger of the structural and environmental control systems at A-AUS and C-IND or use of stair wells that allow, circulation, daylight and air flow at B-AUS and D-IND demonstrate the value in considering environmental control strategies at the inception of the design process to both building budget and operation. The efficiency of the building fabric and design is borne out in the actual energy efficiency performance ratings for A-AUS and B-AUS. While the aspirations of the hybrid AC system could not be realized at C-IND, both the C-IND and D-IND are excellent case studies of how designers can rise to challenges of considering appropriate technologies, local materials and skills and mitigating the overwhelming embodied energy associated with high performance glazing shipped across the seas.

Comfort expectation of the users and thermal set points play a key role in influencing the extent to which the building operates in either active or passive mode. As discussed in Thomas & Thomas (2010), lease agreements and guidelines for tightly controlled settings 22.5±1 °C entrench reliance on AC and pre-condition users to expect these conditions. Although both Australian buildings were originally designed to operate at 19-25°C, there is more to a mixed mode of operation than simply stipulating wider temperature bands. As seen in A-AUS, the risk to performance is intensified when occupants perceive very little control or adaptive opportunity and problems are not rectified quickly. The contrasting **proactive and user responsive approach to building design and management** as seen in B-AUS and D-IND, signals the importance of this approach for successful mixed mode buildings.

C-IND and D-IND are significant in that they buck the more recent trend of year-round 100% AC in contemporary workplaces in Delhi (Thomas et al, 2010) and operate a seasonal AC mode where systems are completely switched off in the mild season. Under this paradigm, two facts are noteworthy – (a.) There is a tacit acceptance of some level of discomfort that could occur in the mild season, but consistent discomfort (as seen in C-IND during the extreme summer conditions before AC was installed) is not acceptable. And (b.), occupants in these contemporary and well-appointed workplaces, who undertake professional, administrative and technical work, consistently demonstrate **a tolerance to much higher temperatures in the subcontinent even in the air-conditioned mode**. The actual thermal sensation (avg_ash, Table 2) is consistently reported cooler than predicted using the PMV-PPD model (avg_pmv) showing a tolerance of warmer temperatures. The emerging results suggest neutral operative temperatures for these particular buildings are 26-27°C in summer/monsoon and 22°C in winter – which is consistent with an adaptive model of comfort (deDear and Brager, 1998).

This brings us to **potential energy savings with mixed mode under different set-points**. Figure 2 shows simulation results (using EnergyPlus) for a 5zone building model under different set-points in Sydney and Delhi. The building envelope and internal load schedules are set to comply with local (ECBC for Delhi; BCA for Sydney). For simplicity, heating and cooling set-points were held constant throughout the year, and the model allows a free running mode whenever external conditions are conducive to maintain stipulated temperature ranges. The ranges tested were 19-25, 20-24, 20-26, 20-28, 22-26 and 22-28°C. With cooling energy being more than 90% of total energy, the discussion below focuses on the impact of varying the cooling set-point on an equator facing perimeter mid-level zone.

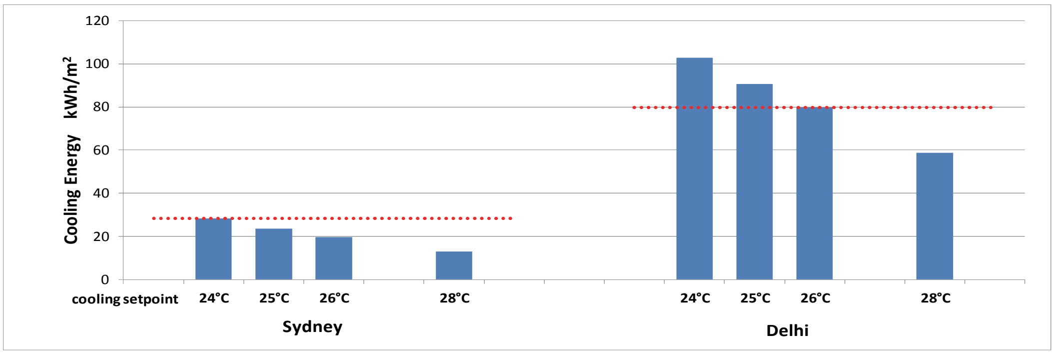


Figure 2 Predicted cooling energy at different cooling set-points for Sydney (north) and Delhi (south)

The results show cooling energy decreases by roughly 12-13% for every degree rise in the set-point temperature in both cities. This concurs with other studies (Ward &White, 2007). The change from the current baseline of 24°C for Sydney and 26°C for Delhi suggests the scale of savings possible. In the case of Sydney, it clearly shows savings of 17% and 31% of the cooling energy at 24°C if the set-point was raised to 25 and 26°C. The results for Delhi show a further 25% of savings would arise by raising the set-point to 28°C[2] from the current set-point, but more importantly we can see substantial increases to cooling energy of 14% and 29% if cooling set point was lowered to match western workplaces at 25°C or 24°C. It is the scale of such a shift that is concerning, given that the actual cooling energy for an office in Delhi is about three times the energy for an office in a more benign climate like Sydney.

TOWARDS EFFECTIVE MIXED MODE BUILDINGS

With respect to the Indian context, the study is a wakeup call to **question the fully air-conditioned approach for the subcontinent** – This is emphasized through the demonstrable tolerance of higher temperatures in the Indian buildings, the energy impost from lowering temperature set-points, and the western experience that narrow limits only serve to entrench air-conditioning. This is more urgent given that the projected increase of built floor space and the warmer climatic conditions will only exacerbate the dependence on fossil based energy. Clearly, it is necessary to harness local capacity for sensible design of mixed mode buildings that cater to India's contemporary workplace needs and shift away from climate rejecting air-conditioned buildings that mimic the worst of many "developed" countries.

In the Australian context, it is ironic (yet unsurprising) that the vicious cycle of air-conditioning and expectations for a narrow band of temperatures continuously negate the possibility of free running and mixed mode buildings despite the benign climatic conditions in cities like Sydney and Melbourne where the potential for such buildings is arguably higher. Here the challenge becomes "**how do we tease occupants out of the highly controlled work environments they have come to expect**?"

Across both contexts, designers need to **explore opportunities to combine mixed mode design with attributes that users like.** As seen in this study, while a lack of occupant control is not perceived as an issue when systems are responsive, occupants can be forgiving of minor discomforts when other positive attributes are included such as connection to the outdoor, daylight, flexible workspaces and amenities. The study also shows that increased adaptive opportunity tends to increase tolerance of a wider band of temperatures. These outcomes confirm other studies (Baker & Standevan, 1996, Leaman & Bordass, 2001 and Leaman et al, 2007), but more importantly they provide us with a "way –in". Rather than considering the office as a homogenous work environment with standardized conditions to be met at all times, an alternate approach would be to seek out functional areas that would benefit from fresh air, daylight etc. Until recently such areas isolated from central air-conditioning have formed only

[2] The 28°C corresponds to an upper limit of 2 degrees above a neutral temperature of 26C that would still deliver a 90% acceptability.

a small percentage of floor space (B-AUS, Drake et al, 2010). However as new ways of "activity based working" are promoted, a higher percentage of floor area is being devoted to break out spaces, café style work environments and flexible zones. As occupants are also encouraged to change location based on their activities, these spaces lend themselves to a mixed mode of operation with adaptive opportunity.

The findings of this paper challenge designers to rethink spatial and environmental opportunities in the context of the changing workplace when shifting the norm towards effective mixed mode buildings. A well designed mixed mode building that is conceptualized and operated from a user centered approach has the potential to drastically reduce the carbon footprint of the building whilst enhancing occupant satisfaction. It presents the opportunity to leap-frog the energy intensive paradigm of air-conditioned building when choosing the way forward for both developed and developing societies.

ACKNOWLEDGMENTS

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Integration of a Comprehensive Stochastic Model of Occupancy in Building Simulation to Study how Inhabitants Influence Energy Performance

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ABSRACT

Building energy simulation (BES) is currently used to design comfortable and energy efficient buildings, e.g. by comparing architectural alternatives. However, usual assumptions on occupancy are too simplistic and do not correspond to real situations. According to performance monitoring experiments, measured buildings consumptions are generally higher than predicted ones. Among the causes of these differences, the role of occupant's behaviour is identified as particularly important. In the tools used by professionals, occupancy is modelled by conventional ratios (e.g. number of persons per m²) and profiles. Besides being inaccurate this representation leaves no place for diversity. On the contrary, the stochastic model presented here takes into account households' and inhabitants' variability in terms of socio-demographic characteristics, schedules, use of electrical appliances, and adaptive behaviour. Instead of one simulation with conventional scenario leading to a unique energy consumption value, a series of simulations is conducted and yields a statistical distribution. For each simulation, virtual households are created through a probabilistic procedure according to dwellings' properties and each occupant is defined by a set of characteristics (age, sex, employment status, etc.). These characteristics condition households' electrical appliances ownership and occupants' activity scenarios, generated through a stochastic model calibrated on data from a French Time Use Survey (TUS). The activity scenarios are used as inputs to simulate the use of electrical appliances, and predict adaptive actions (depending on external and ambient conditions). A case study on a residential building located in Lyon (France) illustrates how the energy consumption probability distribution obtained after a thousand simulations can be used in a process of energy performance guarantee (EPG).

INTRODUCTION

Many monitoring experiments performed in the past years on new or retrofit buildings revealed that buildings energy consumptions exceeded the previsions of the simulation tools. This gap can partly be explained by differences between the real building envelope and the simulated one but it seems that the effective conditions of occupancy play an even more important role. Andersen (2012), for example, highlighted this point by observing very dispersed annual heating consumptions for similar dwellings

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under the same climate. Moreover, the role of occupant's behaviour is particularly important in efficient buildings whose performance is very sensitive to solar and internal heat gains as well as to heat losses due to ventilation. In the simulation tools, occupancy is modelled by conventional ratios and profiles. A new approach is necessary to increase the relevance of simulation results (in terms of energy consumption and thermal comfort), avoid design errors and represent behavioural diversity. Controlling the uncertainties related to occupancy is also essential to develop a process of EPG, currently a major issue for the building sector. An original model of occupancy that tackles this issue in the case of residential buildings is described in the second part. The third one presents its application to the issue of EPG. Suggested improvements for the model and possible applications are discussed in the conclusion.

DESCRIPTION OF THE INTEGRATED BEHAVIOURAL MODEL

The proposed integrated behavioural model is composed of several submodels in order to:

- create realistic virtual inhabitants defined by a set of socio-demographic characteristics (no equivalent model has been found in the literature),
- generate inhabitants' activity scenarios according to their characteristics, using the detailed model developped by Wilke et al. (2013), which was calibrated with data from a TUS,
- equip households, and describe appliances' duty cycles and standby power – data from surveys were used to define ownership probabilities depending on households' characteristics and measurements were used to generate a diversity in appliances' characteristics, while reference models (Richardson, Thomson, Infield, & Clifford, 2010; Tanimoto, Hagishima, & Sagara, 2008; Widén & Wäckelgard, 2009) consider the average national ownership rate and a unique power use for each type of appliance,
- simulate the use of appliances – data from measurement campaigns made possible a calibration for each type of appliance, while previous models used a residual electrical power to comply with aggregated dwelling's electricity consumptions,
- simulate actions of occupant's on windows using Haldi and Robinson's model.

The way the different parts of the model are articulated and coupled to the dynamic BES software *Pleiades+Comfie* is summarised in Figure 1.

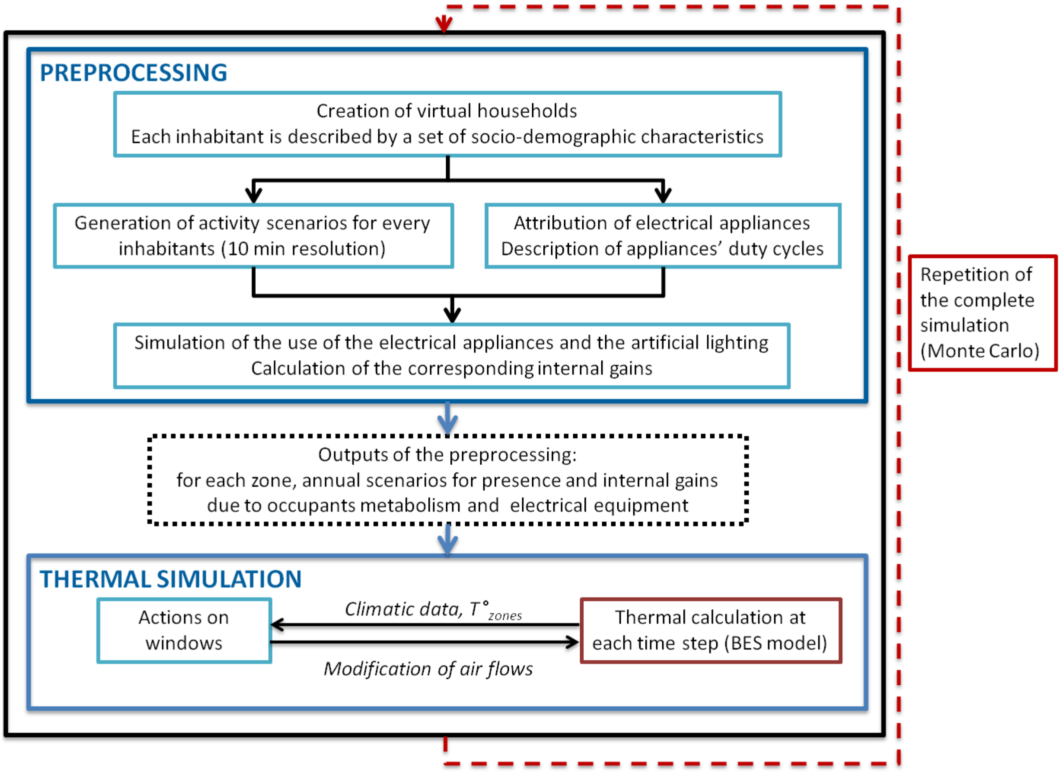

Figure 1 Overall scheme of the integrated behavioural model coupled to the BES.

By repeating the simulation according to the Monte Carlo method, the model generates a distribution of the energy consumption relative to occupancy instead of the usual unique value. Temperature setpoints control is not integrated (indoor temperatures were measured in the building considered for the case study) nor actions on shading devices (which are difficult to model in residential buildings since the driving factors are numerous and vary from case to case : the role of temperature and privacy can be important, whereas the link with visual comfort is strongly prominent in office buildings).

Stochastic creation of virtual households

The first submodel creates virtual inhabitants for every housing at the beginning of a simulation. Since series of simulations are conducted, the same housing is stochastically inhabited by different virtual households at each simulation (e.g. a five-persons family, or a single occupant, etc.). Each inhabitant is described by a set of socio-demographic characteristics that are consistent:

- for a given individual (e.g. the retired status must be in agreement with the age),
- between individuals of the same households (e.g. if the first individual is a married man, father of one child and having a high income level, his wife and child must be generated too, their ages must be consistent and they must share his living standard),
- between inhabitants and the housing, for which the simulation tool user is always able to provide the location (urban/rural), the number of rooms and the type (detached house/apartment/other).

Individuals' characteristics are strongly intercorrelated, therefore they are determined sequentially. From the number of rooms, the type of housing and the location there are probabilities for different number of members of the household; knowing the size of the household there are probabilities for different types of households; knowing the type of household there are probabilities for the age and gender of his reference member, etc. The whole procedure draws on large datasets from the last population census in France and associated surveys.

Generation of activity scenarios for each occupant

Presence and activities modeling allows localising the inhabitants in the different rooms and assigning corresponding metabolic heat gains. But more importantly, it is a necessary input to simulate the adaptive actions and the use of appliances and lighting. Wilke et al.'s model (2013), based on Markov processes and multinomial logit models, was adapted to provide weekly scenarios (then reproduced identically for every week of the simulation) for every inhabitant. In this model, the probability to start an activity and the associated distribution of duration both depend on the day of the week, the time of the day, and the socio-demographic characteristics of the individuals. To illustrate its outputs, Figures 2 and 3 respectively present the average daily profile of the activities for a population of 15,441 people (corresponding to the individuals of the TUS) and a daily scenario for a random occupant.

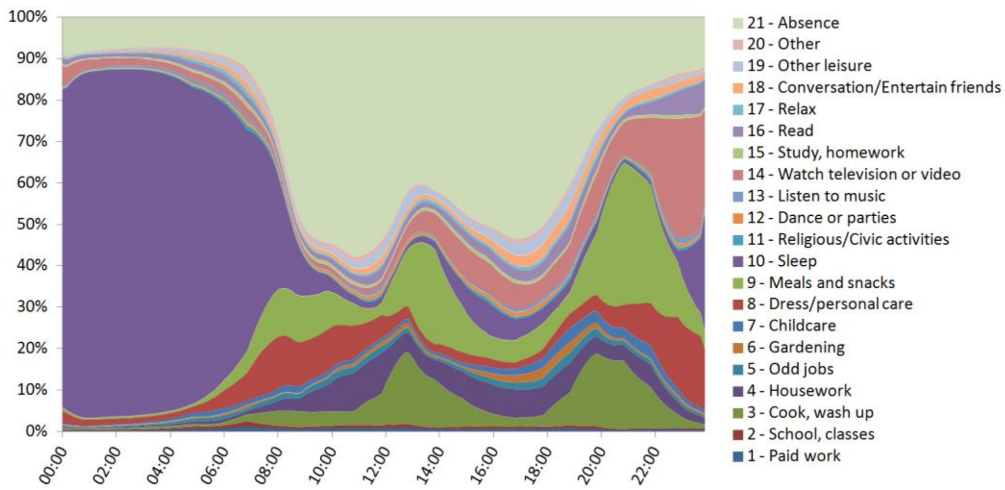

Figure 2 Average daily profile of the activities for a population of 15,441 individuals.

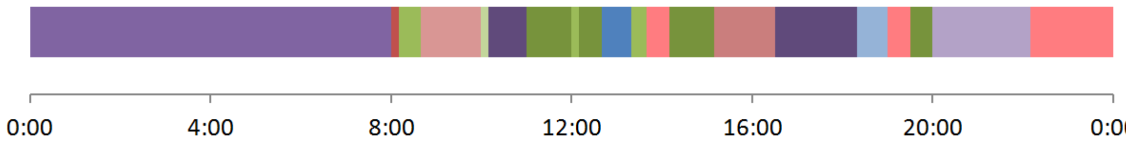

Figure 3 Example of a daily scenario for a random individual (the colors legends are the same as in Figure 2).

Before linking activity scenarios to appliances operation, households have to be equipped and their equipments described. For all these steps, the example of the dishwasher is used as an illustration.

Households' electrical appliances ownership

This submodel equips households with appliances, according to probabilities relative to their characteristics. More than thirty appliances are modeled, including several instances of the same equipment (e.g. principal and secondary television or computer have different characteristics). According to the type of appliance, probability of ownership corresponds to the average national rate, or depends on the age of the reference person[1] , the type of household, its income or a combination of these factors. In the case of dishwashers, probabilities of ownership are determined as functions of the type of households and its income (c.f. Table 1) according to results from (INSEE, 2012).

Table 1. Dishwashers' Probabilities of Ownership

Household type\Income quartile	1st	2nd	3rd	4th
One person household	25 %	30 %	35 %	40 %
Couple alone	60 %	65 %	70 %	80 %
Couple with children	65 %	80 %	85 %	90 %
Single-parent family	35 %	45 %	45 %	55 %
Other type of household	45 %	50 %	50 %	70 %

Description of appliances' duty cycles

This submodel assigns a duty cycle (constituted of a square signal or a succession of square signals) and a standby power to each appliance. Appliances of a same type can have various operating powers according to their technology, dimension and preferred mode of use. Data are mostly provided by several comprehensive measurement campaigns realised by the engineering office ENERTECH in partnership with EDF and ADEME[2]. For instance, 65 dishwashers' consumptions were measured with a 10 min resolution during one year (ENERTECH, 2008). Dishwashers' duty cycles can be divided into four phases. Water is heated during phases 1 and 3 while cold water is used in phases 2 and 4. A fifth phase of active drying is optional. Each appliance is associated with a nominal power ranging from 1,500 to 2,100 W[3]. Phases correspond to a percentage of this power and a duration (both potentially variable). In agreement with observations of the campaign, an appliance in a specific household is associated to a unique duty cycle. Table 2 summarises the description of the operating phases.

Table 2. Dishwashers' Duty Cycles

Phases	N°1	N°2	N°3	N° 4	N° 5
% of the nominal power	100	10 - 30	40 - 80	5	40 - 80
Duration (min)	20	10 - 60	20	10	5

[1] The "reference person" is a demographic concept which indicates a kind of "head of the household".

[2] EDF : Eléctricté De France ; ADEME : Agence De l'Environnement et de la Maîtrise de l'Energie

[3] Maximal power can be higher but peak loads occur on periods much shorter than the 10 min time step of the model. A superior temporal resolution isn't necessary to evaluate heat gains in a building or even to model the electricity demand of several housing units because of thermal mass and averaging effects.

A seasonal coefficient is affected to the nominal power to reflect the cold water temperature variation. The three values of the coefficient, corresponding to winter, summer and midseason (respectively 1.09, 0.82 and 0.98), were obtained by dividing the measured average daily consumption of the period by the measured annual average daily consumption. Figure 4 shows a good agreement between the modeled cycles consumptions and the measured ones.

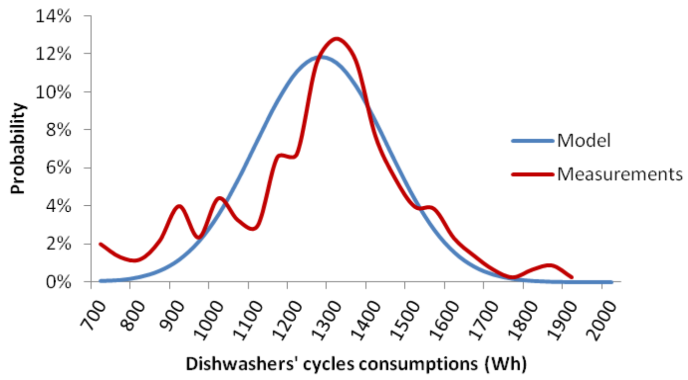

Figure 4 Comparison between modeled and measured cycles consumptions.

Simulation of the use of appliances - Starting probabilities calibration

The use of appliances is linked to occupants' activities through pragmatic hypotheses. In the case of dishwashers, it is assumed that they operate just after the end of a meal. Therefore, every time a period of "Meals and snacks" ends, a random number is sampled on [0, 1] and compared to the dishwasher starting probability to determine wether a cycle begins. For a few appliances, among which dishwashers, time delay functions are integrated to allow shifting the starting time. In the case of dishwashers, delays mostly concern after-dinner cycles, when people do not need to use the appliance before the next morning. Shifting is then used to benefit from lower electricity prices of the night. To have a number of cycles during the night in coherence with measurements it is supposed that 25 % of the cycles between 6 p.m. and 11 p.m. are shifted after 11 p.m., with an average delay of 4 hours. A main objective of the model is to accurately reproduce the load variations during a day. To do so, the starting probabilities are calibrated as functions of the hour, so that the average daily load curve obtained through a great number of simulations fits the average daily load curve taken from the measurements. Figure 5 illustrates the obtained similarity of the two curves (the root mean square error per hour is 2.3 Wh) using the calibrated starting probabilities presented in Table 3.

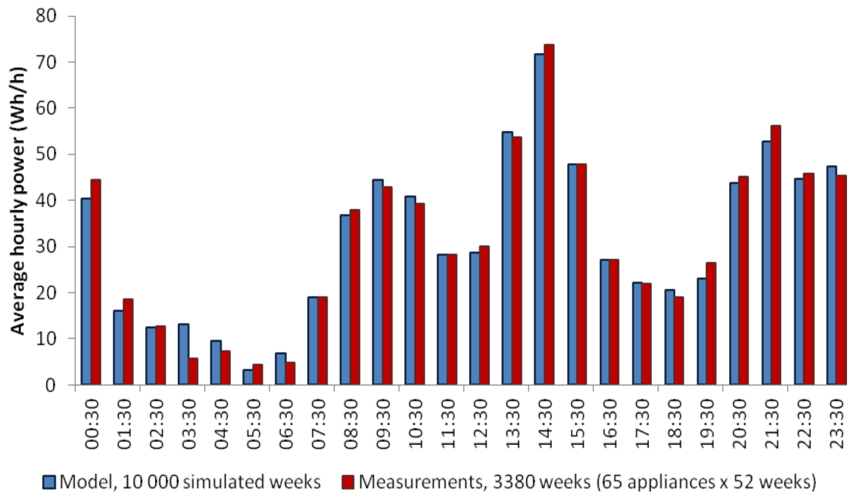

Figure 5 Comparison of the modeled and measured average daily load curves.

Table 3. Dishwashers' starting probabilities at the end of a meal as a function of time

0h - 8h30	8h30 - 13h	13h - 14h	14h - 19h	19h - 21h	21h - 24h
0.10	0.16	0.22	0.17	0.25	0.15

Simulation of the use of appliances - Evaluation of the ability of the model to produce diversity

By choosing this way of calibration, it is ensured that the model reproduces an average number of cycles and an average annual consumption that are in good agreements with measurements. It is also necessary to evaluate its ability to produce a realistic diversity. The proper behaviour of the model on that point is illustrated by Figure 6 which shows, for example, that 10 % of the dishwashers have a consumption higher than 500 kWh/year.

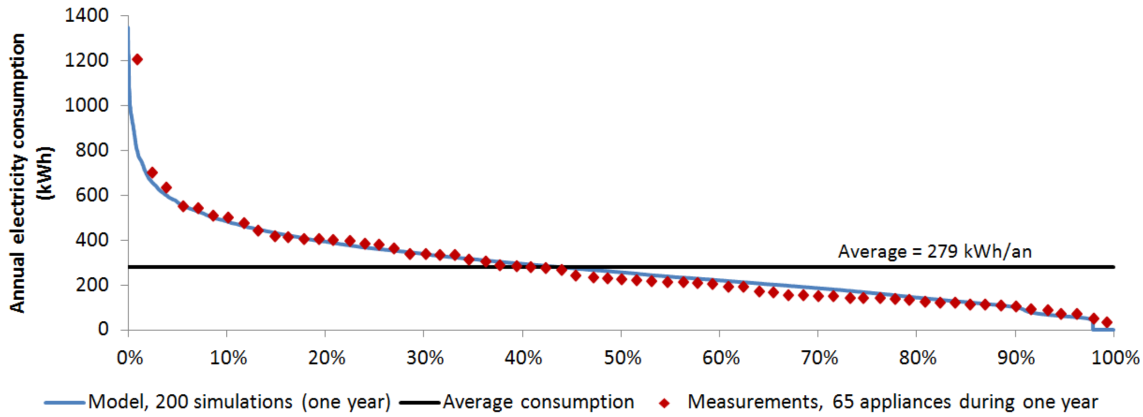

Figure 6 Comparison of the modeled and measured annual consumptions.

Application of the electrical consumption model including artificial lighting modeling

Artificial lighting use is modeled similarly to appliances, except that switch on probabilities depend on the hours of sunrise and sunset. The calibration data are provided by annual measurements of every light bulbs in 100 housing units in France (ENERTECH, 2004).

As an illustration of the whole electrical consumption model outputs, Figure 7 presents a load curve of a random four room apartment for the first week of the year (Monday 1th.january to Sunday 7 th). Appliances are regrouped by type (e.g. dishwashers are part of the "washing" group with washing machines, tumble dryers, clothes irons and vacuum-cleaners).

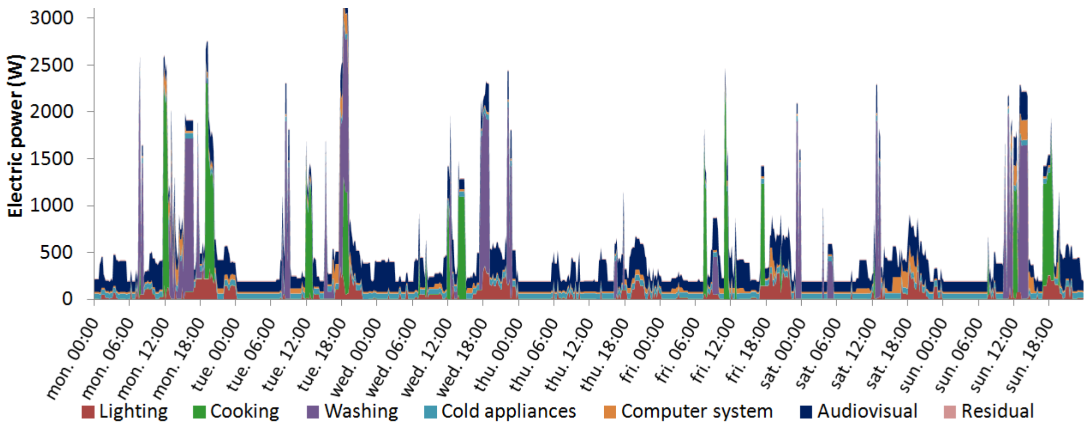

Figure 7 Example of a weekly electrical load curve for a four room apartment.

One can observe for instance the importance of standby consumption of the audiovisual part for this housing and the concentration of peak loads around 8 a.m., noon and 7 p.m. The derived internal heat gains scenario presents the same trends with lower peaks because only part of the electric energy consumption is converted into heat gains (e.g. for dishwashers 40 % of the energy is lost as greywater).

Occupants' actions on windows

Whereas the previous submodels were part of a preprocessing that may be seen as a "scenario generator", windows' openings and closings interact with the thermal calculation at each time step since such actions depend on inside and outside temperatures, while air flows influence the heat gains or losses. Haldi and Robinson's model (2009) is used for this part. Its predictions address the binary action "open/close" but gives no indication on the opening rate. Therefore, when an opening happens, an entering airflow is sampled between 5 and 15 vol/h and assumed constant during the opening duration.

APPLICATION TO EPG OF A RESIDENTIAL BUILDING

One objective of the integrated behavioural model is to assess the uncertainties related to occupancy in order to develop a process of EPG. In this context, we studied a 4 storeys residential building with a 1,048 m² area located in the suburb of Lyon. It includes 16 apartments, modelled by a thermal zone each, plus a central circulation corresponding to a seventeenth zone (Figure 8 a). The exercise carried out in this case study was the following one: this building was retrofitted including an insulation of the outside walls; heating consumption, air exchange, and indoor temperature were measured before the renovation; the goal was to estimate the heating consumption after the renovation with a confidence interval allowing the project manager to make a commitment on a guaranteed performance. Then, this performance was compared to the actual consumption, which was measured during the year following the renovation. The uncertainty due to occupants' behaviour was calculated with the Monte Carlo method (1,000 simulations including the integrated behavioural model were conducted to draw a smooth gaussian distribution of the heating loads but fewer are required to reach the convergence on the average value and the standard deviation). The thermal characteristics of the building after renovation are given in Table 4. Results are summarised in Figure 8 b.

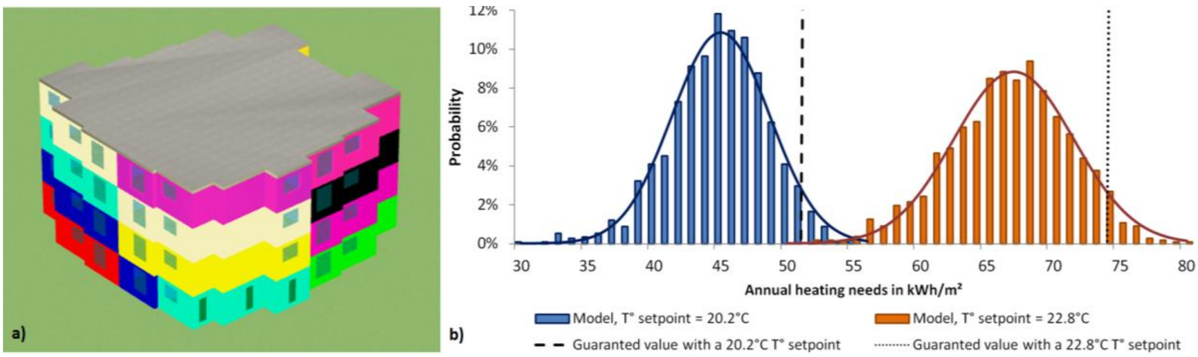

Figure 8 (a) Thermal zones of the building (design interface of the simulation tool *Pleiades+Comfie*). (b) Heating loads distributions for two temperature setpoints corresponding to measurements before and after renovation.

We first consider that the heating temperature was maintained to its value before renovation (approached by a 20.2 C constant scenario). Using this heating scenario and scenarios from the French regulatory method for presence and internal gains[4], the annual heating loads were 38 kWh/m², whereas the Monte-Carlo method leads to an average value of 45 kWh/m² with a standard deviation of 3.5 kWh/m² (blue curve). Accepting a risk of exceeding of 2.5 %, the guaranteed performance would be 52 kWh/m². The average value for annual heating loads and the guaranteed performance threshold were respectively 18 % and 37 % higher than the value obtained through the regulatory calculation method.

[4] Presence and internal gains during the night and the week-end. Using also the conventionnal scenario for heating (19 °C during presence), the calculated annual heating loads were 29 kWh/m².

The actual loads (62 kWh/m²) were superior to the guaranteed performance value, essentially because of a "rebound effect" on the heating setpoint : average temperatures measured in winter after the renovation approached 23 °C (compared to 20.2 °C before). Guarantee obviously cannot longer apply if the requirements of the inhabitants increase after the renovation. For such a heating setpoint (red curve), the guaranteed performance would have been 75 kWh/m².

Table 4. Thermal characteristics of the building

Facades	U = 0.22 W/(m².K)	Thermal bridges	Psi = 356 W/K
Loggias	U = 0.23 W/(m².K)	Mechanical ventilation flow	0.3 vol/h
Low floor	U = 0.49 W/(m².K)	Air infiltrations flow	0.15 vol/h
Roof terrace	U = 0.29 W/(m².K)	T° setpoint before works	20.2 °C
Windows	U = 1.9 W/(m².K)	T° setpoint after works	22.8 °C

CONCLUSION

A comprehensive stochastic model of occupants' behaviour in residential buildings is proposed. It integrates an original model for the creation of virtual individuals described by a set of socio-demographic parametres. This allows a high degree of refinement in the generation of schedules and in the attribution of equipment to households according to statistical data. The use of appliances and lighting is modeled on the basis of inhabitants' activities with a higher accuracy than existing models from the literature, through data from several large measurement campaigns. A reference model for interactions of occupants with windows was adapted. The whole model is coupled to a dynamic BES tool with no more necessary input than the building description (but any available information on inhabitants' characteristics or equipment can be filled by the user). The distribution of the simulation outputs is than obtained using the Monte-Carlo method. In the case study, it was observed that the monitoring of temperature setpoints in winter is essential in a process of EPG (knowing that it can be easily and reliably implemented at low cost). If not, considering the possibilities of evolutions of the temperature setpoints leads to a wide distribution, unexploitable in this context. However, this aspect being under control, a commitment on a guaranteed value becomes possible. In this case the guaranted value would be 38 % higher than the value calculated with conventionnal deterministic scenarios.

In further studies the whole coupled model will be encapsulated within the statistical software R. The influence of different parametres of the integrated model will be analysed to identify the aspects on which attention should be paid in terms of improvement and data collection. The outputs of interest will include heating loads but also domestic electricity consumptions and comfort indicators.

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Assessing Pedestrian Thermal Comfort within the Buenos Aires Climatic Context

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ABSTRACT

With over 50% of the world's 6 billion people presently living in metropolitan areas and an estimated 70% projected by the year 2050 (UN-Habitat, 2010) urban environments have become the mean scenery for human activity. These environments are strongly subjected to the effects of buildings which shift wind patterns and limit solar radiation exposure. This research is a study on how these changes may directly affect the Buenos Aires city inhabitants. The methodology consists of three subsequent steps.

Firstly, three daily two hour time frames have been identified for the morning, midday and afternoon period. These represent three daily cycles for when pedestrian activity is at its highest. In addition, the climate was analyzed and the months were grouped into three climatic periods, cool, mild and warm. Both these studies have been crossed creating a nine time frame schedule which mixes climate and outdoor activity.

Secondly, iterations were carried out within each time frame in order to analyze the combined effects of air speeds and solar radiation levels upon the Physiological Equivalent Temperature (P.E.T) proposed by Hope (1998).

Lastly, the resulting P.E.T. has been weighed against De Dear's adaptive thermal comfort equation proposed for indoor scenarios (De Dear, 1997). The amount of hours in which the resultant P.E.T. was within the established 90% acceptability for the different combinations were noted creating a trend for each of the nine time frames, represented by the comfort graphs.

These graphs show which combinations of air speed and solar radiation are going to be preferable over others for sedentary activities during the times when people tend to be outdoors. It was concluded that during the months with the cooler temperatures and lower solar angles, solar availability becomes less important thermally than wind protection, and vice versa.

INTRODUCTION

This investigation sets the bar for assessing open urban spaces in order to provide tools which work towards more thermally responsive metropolitan environments. Drawing people outdoors and prolonging their stays contributes to a more lively city offering greater interaction between its citizens, and encourages lower levels of energy consumption. For this case study, the city of Buenos Aires was chosen as a setting, as it presents a climate without extremes which could be exploited for sedentary activities throughout the year.

Initially, the climate data will be analyzed and broken down into three groups composing the annual cycle. Additionally, three key time frames are selected for their characteristic peak outdoor activity breaking down the dayly cycle. As a result of this section, 9 time frames (3 for each of the 3 periods) are tagged as representative and identified as a schedule for outdoor occupancy.

Subsequently, the physiological equivalent temperature (PET) comfort model proposed by Hope (1998) is assessed and compared to Fanger's (1970) predicted mean vote (PMV) model. Both these models are then related to each other and to comfort. Moreover, to account for user adaptation, an adaptive thermal comfort model proposed by De Dear 1997) is also balanced with the previous two models and comfort. PMV and PET simulations were carried out for a hypothetical individual. Using the results of these simulations, equations are estimated for predicting the effects upon PET of changing one's clothing or metabolic rates. These equations are then carried for calculating the PET in a sedentary state with the Clo values corresponding to each of the climatic periods. Iterations are then carried out to understand the combined effects of solar and wind exposure upon PET for each of the established time frames. The results of these are then plotted into 9 comfort graphs corresponding to the nine time frames, showing the most desirable combinations of sun and wind exposure for each.

Finally, the effect of altering one's exposure to sun while maintaining the same air speed during one time frame is related to the °K difference on PET. These results are then again plotted into one graph for each period assesing the extent of the addaptive opportunities individuals may have in outdoor scenarios.

The main contribution of this paper is to show for the nine time frames, which are the most favourable combinations of solar radiation and wind speed for sedentary activities to develop in the Buenos Aires climatic context. This mothodology may wall be translated and applied for different climates.

CLIMATE ANALYSES FOR OUTDOOR SEDENTARY ACTIVITIES

The weather data for the city of Buenos Aires (34°36'S; 58°22'W) here presented in Table 1. It is the data extracted of an average in the form of a typical metereological year for the period between 1995 and 2005. In the table one may see how the abrupt changes of mean dayly air temperature (column 2: Tm) was used to break down the annual cycle into a warm, mild and cool period. The former period does not present exceedingly high air temperatures at an average mean of 23°C. Nevertheless, the high levels of solar radiation along with absolute humidity recordings close to the limit recommended for comfort of 12 g/kg (Szokolay, 2008), could contribute to discomfort. During the mild period the mean temperature takes a step down going to mean dayly values in between 15 to 20°C. However, there is still a high availability of solar radiation which in this scenario could be exploited. Finally, the cool period presents mean dayly air temperatures in the range of 10 to 15°C which could potentially limit the development of outdoors sedentary activities.

Table 1: weather data for the city of Buenos Aires (34°36'S; 58°22'W)

Month	Tm °	Tmin °	Tmax °	AH g/kg	RH %	GGhor kWhr/m²	GDhor kWhr/m²	Wind m/s
Jan	24.4	16.3	32.8	13	67	7.1	4.3	3.5
Feb	23.0	14.9	31.8	12	70	6.5	4.1	3.5
Mar	22.0	13.6	29.7	12	72	5.2	3.2	3.3
Apr	17.6	9.4	27.1	10	76	3.8	2.3	2.9
May	14.8	7.0	24.5	8	78	2.8	1.7	2.7
Jun	12.0	4.0	21.0	7	80	2.2	1.0	2.6
Jul	11.0	3.1	19.9	6	77	2.3	1.2	2.8
Aug	13.0	5.1	24.5	7	75	3.2	2.0	3.1
Sep	13.9	5.6	22.3	7	70	4.3	2.4	3.5
Oct	17.7	8.5	26.0	9	71	5.3	2.9	3.9
Nov	19.8	10.7	30.6	10	70	6.8	4.4	3.9
Dec	22.5	12.9	31.7	11	64	7.0	3.7	3.8

Source: meteotest, 2006

TIME FRAMES

Outdoor spaces are extremely sensible to quick changes as time passes, therefore, it is important to isolate periods of time of higher relevance creating an outdoor "schedule". This schedule is meant to address the time frames when outdoor activity is at its peak. These peaks tend to happen when people move from one building to the other usually matching rush hour times in the morning and the afternoon. Additionally, there is a drastic peak of pedestrian activity at midday when people go out for lunch. Therefore, three daily time frames have been established as of key relevance for people to be lured or to remain outdoors:

Crisscrossing these three time periods with the three previously established climatic periods gives way to the nine "time frames" (TF) which serve as a setting for this investigation.

PEDESTRIAN THERMAL COMFORT

The Rayman© research tool (Matzarakis & Rutz, 2006) was used for the comfort simulations, which require the inputs shown in Table 2 and estimates both, PET and PMV. The inputs required for the simulations are grouped into *external* and *personal* parameters. The former group varying with the context presented and the later depending on the different individuals. In this case the hypothetical individual here presented.

Table 2: Presentation of the simulation parameters and data

Inputs	Parameter	Simulation Data
External	Julian Date	Time frame
	Time	Time Period
	Air Temperature	Time Frame
	Relative Humidity	Time Frame
	Wind Velocity	**Iterations**
	Cloud Cover	Time Frame
	GGhor	**Iterations**
Personal	Gender	Male
	Weight	75 Kg.
	Height	1.75 m.
	Age	30
	Activity	Sedentary 100 W
	Clothing	**Climatic Period**

For the simulations, mean air temperature and relative humidity was taken from each of the established nine time frames. However, for the solar radiation and wind velocity parameters, iterations were run. Solar radiation was simulated with increments of 100 W/m², and the upper limit was established by the maximum average found in the given period. Similarly, air speed iterations were run with increments of 0.5 m/s, and the upper limit for all time frames is set at 5 m/s which is the established maximum acceptable air speed for outdoor sedentary activities (Nikolopoulou, 2002).

The personal inputs were fixed for the values of a hypothetical individual while performing a sedentary activity. The only variable in this case is therefore the Clo input, as it is assumed that the same person would dress differently on relation to the climatic periods. Thus, this variation follows the yearly cycle, but not the daily one.

ESTABLISHING A RELATIONSHIP BETWEEN PET AND PMV WITH THERMAL COMFORT

As PMV was developed in a comfort chamber it is usually a tool made for assessing indoor comfort (Fanger, 1970), while The PET model was developed for translating outdoor combinations into a thermal equivalent. Moreover, the former model could be related to comfort through the percentage of people dissatisfied (P.P.D.) while PET only gives a thermally equivalent temperature, which leaves the question of how comfortable one is unanswered. However, this model has been previously related to comfort (Matzarakis & Mayer, 1996) by estimating a fixed level of thermal stress corresponding to each thermal sensation. Although it is a significant contribution, this relationship does not consider personal adaptation to the annual climatic variations as it is the same sensation regardless of the climatic period. In order to account for user climatic adaptation, a link between PET and a model of adaptive comfort needed to be established. The model chosen for this task was the one presented by De Dear et. al. (1997) originally intended for indoor settings and here presented in equation (1). The fact that PET is the thermal equivalent to an indoor setting is what allows for an effective comparison between these two models.

$$Tn = 17.8 + 0.31Tm \qquad (1)$$

Tn : Comfort temperature
Tm.: Monthly mean temperature

ubsequently, to plot the adaptive comfort band for 90% acceptability, De Dear et. al. (1997) suggest adding and subtracting 2.5°K to the Tn. The results of the application of this model and its band to the presented climate of Buenos Aires is here plotted in Figure 1. The three climatic periods previously presented are overlaid, establishing the upper and lower limits of adaptive comfort for 90% acceptability for each period.

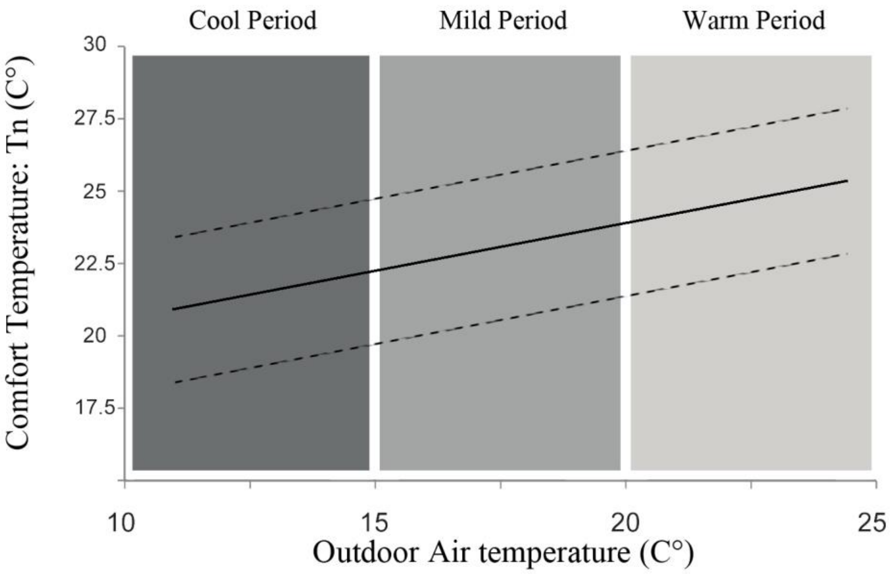

Figure 1: Adaptive comfort equation and 90% acceptability band presented for the year.

Finally, the association is made between all the models and the degree of thermal stress as can be seen in Figure 2. To the left of the figure, the association presented by Matzarakis & Mayer (1996) is shown while to the right, the association is made with the model of adaptive comfort using the limits for each period found in Figure 1.

The initial link by Matzerakis and Mayer between comfort and PET resemble the ranges for the calculated bands of the cool period. However, the warmer the period the farther they stray. Therefore, this suggests that according to the adaptive model, people would prefer warmer temperatures during the warmer periods. At this point it needs to be recalled that adaptive model used supposes a limited array of addaptive opportunities commonly found in the interior of an office building. By contrast, in a successful outdoor scenario, the opportunities are plenty such as moving to sunny areas, or exposing oneself to faster air movements. This agrees with the argument that successful outdoor spaces are not those which meet one “optimal” comfort situation at a given time, but rather, offers several (Katschner, Steemers, & Yannas, 2000). Ultimately, this widens considerably the hypothetical comfort band.

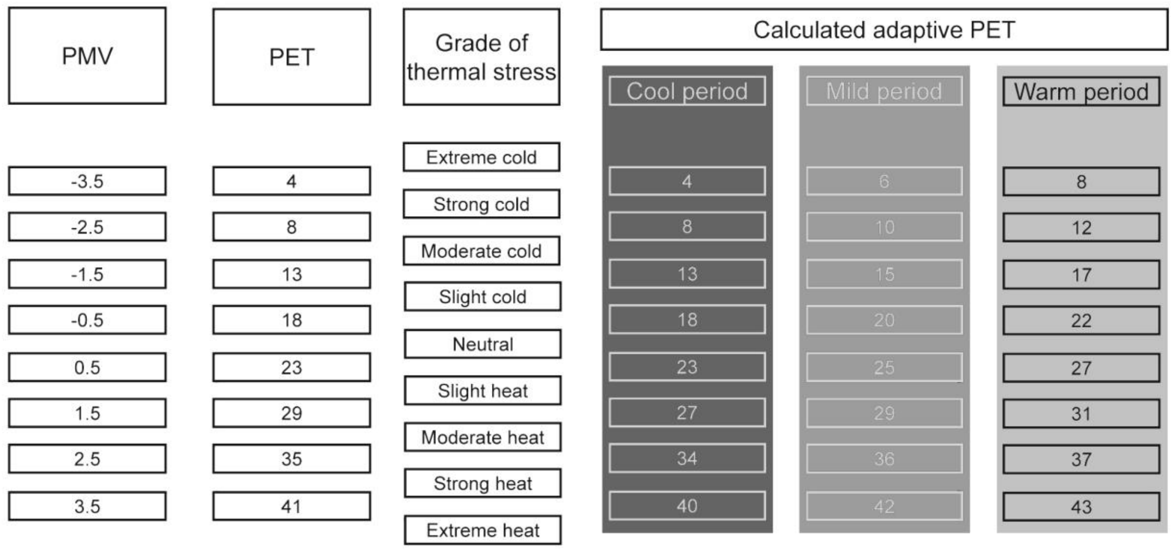

Figure 2: Comparison between PMV, PET and adaptive PET with a grade of thermal stress.
Source: After Matzerakis & Meyer 1996

RELATIONSHIP BETWEEN PET AND PMV

As the Rayman© tool allows the calculation of PET and PMV simultaneously for the same inputs, both results could be related to each other. However, when calculating PET values, the Rayman© tool keeps a fixed value for clothing and metabolic rate of 0.9 Clo and 80 Watts respectively and is not sensible to changes on these parameters. Nevertheless, this is not the case for the PMV simulations which are sensible to changes in all parameters. Therefore, a way to convert PET into PMV had to be addressed to understand the effects of changes in clothing and metabolic rates. For this task, simulations were carried out using the external data for all the days of the mild period during the morning time frame (8:00 & 9:00), for the case of the hypothetical person presented in Table 2 using the fixed values for Clo and metabolic rates (0.9 Clo and 80 W). The resulting PET values where linked to their PMV counterparts. This relationship is here shown in Figure 3.

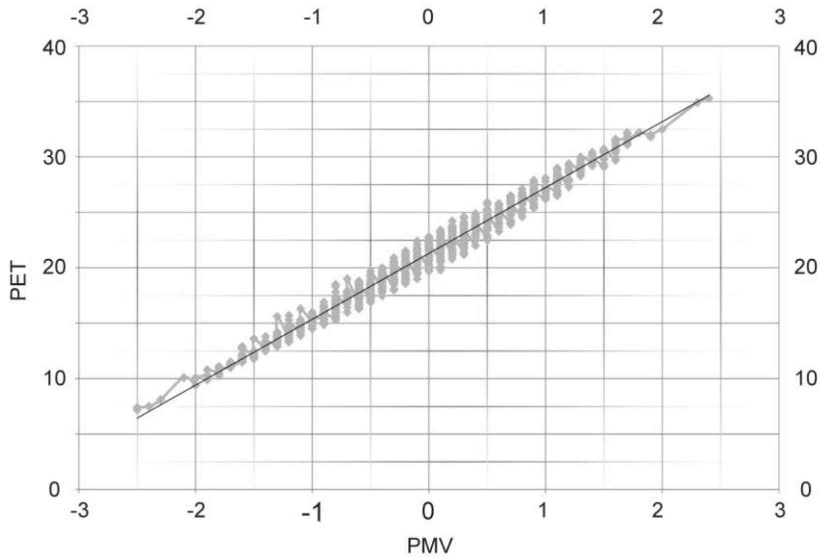

Figure 3: Relationship between PET and PMV for the same inputs.

Once this relationship had been established, the equation that enables the conversion of PMV results into PET was extracted (2).

$$PET = 5.93 \times (PMV) + 21.3 \qquad (2)$$

Through this equation the corresponding changes upon PET for different metabolic rates and/or Clo values became distinguishable. However, to understand the incidential change of one of the parameters, the other one has to be isolated. To accomplish this, runs are made calculating both PMV and PET while maintaining one of the two fixed and the other as a variable. Starting with the incidence upon PET for changes in Clo, a simulation is made for all the hours of the morning time frame during the warm period. For this simulation, the data for the hypothetical person was used with an 80W activity rate (fixed value) and a 0.5 Clo (corresponding to the warm period). The PMV output estimates the 0.4 Clo difference, but the PET does not. Therefore, by converting the PMV into PET' and weighing against the resulting PET, it will be possible to determine the effect of a 0.4 Clo change upon PET. Dividing this difference by 4 allowed to determine the effect of a change in 0.1 Clo for each of the different hours. A similar methodology was followed to determine the effect of a 20W increase or decrease of activity rate upon thermal comfort through PET. Both results are here plotted in Figure 4.

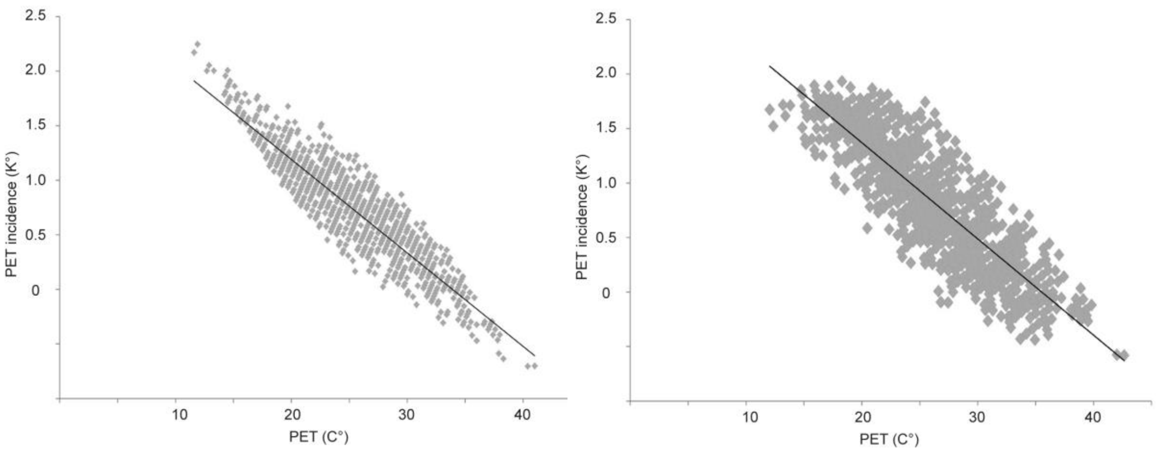

Figure 4: °K incidence of adding or subtracting 0.1 Clo (left) or 20W (right)

Upon observation of these figures, it becomes evident that the cooler the setting, the higher the effects of clothing and metabolic rate. Additionally, due to the similarity between both curves, it may be stated that adding a light pullover (0.20 Clo) is thermally similar to changing one's activity rate from light to medium work intensity (120W and 160W respectively) (Szokolay, 2008), and the increment in PET will be more effective in cooler periods. Both equations are here presented.

$$\text{Incidence of } \pm 0.1 \text{ Clo} = -0.0856 \times \text{PET} + 2.9 \quad (3)$$

$$\text{Incidence of } \pm 20 \text{ W} = -0.092 \times \text{PET} + 3.6 \quad (4)$$

It needs to be stated at this point that both these formulas become less reliable when approaching extremes. This is due to the fact that it is based on a PMV conversion into PET, and it was already found by Nicol & Humphreys (2002) that the former model may not be reliable for temperatures below 10°C or above 30°C. Nevertheless, for the purposes of this study it does not present major problems as the focus is placed within the comfort areas which should be well off the extremes.

APPLICATION OF THE FORMULAS – THE COMFORT GRAPHS

As it becomes possible to convert the effects of both Clo and Metabolic rates, PET simulations for the presented hypothetical person are carried out for each of the presented nine periods. For the warm, mild and cool periods, different Clo values of 0.5, 0.9 and 1.2 were assigned respectively matching Argentinian's cultural trends and responses to climate. The data from all the hours of each of the nine periods was used. Iterations were run for wind speeds from 0.5 to 5 m/s which is the established upper limit for comfort for sedentary activities outdoors (Nikolopoulou, 2002). Similarly, iterations were run for solar radiation starting at 100W up to different limits established by the values found within each climatic period, with intervals of 100W (for the case of the cool period, 50W intervals were used).

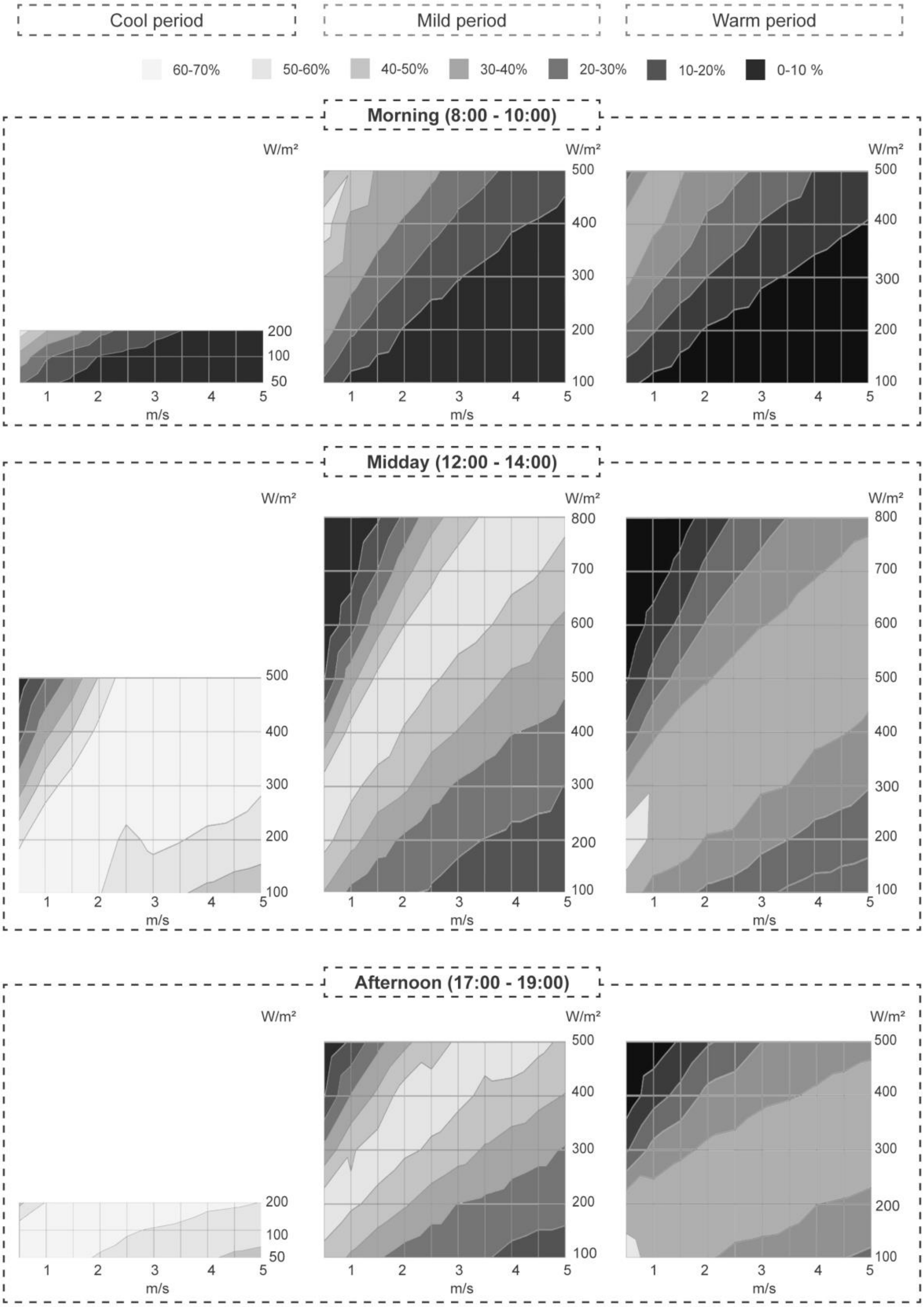

Figure 5: Comfort graphs for each of the nine time frames. Each gradient represents a different percentage of hours in which the simulated PET for the hypothetical individual is within the 90% comfort band calculated for the different combinations of air speed and solar exposure.

All results for each hour were then weighed against the adaptive comfort limits calculated for each climatic period shown in Figure 2. This assessment was carried out to determine the percentage of hours in which the different combinations of solar radiation and air speed result in PET values which fall within a 90% acceptability. This was done so, in order to produce graphs which would have a double entry, solar radiation and air speed, and therefore, understanding the comfort limits offered by a space. The resulting comfort graphs are here shown for all nine time periods in Figure 5.

The graph corresponding to the morning time frame of the warm period (upper right) will be used as an example. Supossing a scenario which presents a global solar radiation of 400W and 3 m/s, it may be distinguished that 10-20% of all of these hours, the hypothetical person will be with a PET value within the 90% acceptability band. This does not mean that these combinations would be uncomfortable 80-90% of the time, but it does mean that overall, a place which offers more wind protection will be more desirable at this moment. Additionally, it can be seen that the cool period presents the widest ranges of comfort. This could be misleading however, as this is mainly due to the effect of higher clothing which has a stronger effect under colder conditions rather than a reliance on the external conditions. Finally, the more slanted the lines are, the higher the effect of solar radiation in the given period and vice versa. Therefore, it may be concluded that thermally speaking, clothing takes precedence over the effects of solar radiation and air velocities during the cool period, yet wind protection is more highly desirable.

CONCLUSION

With the use of the comfort graphs presented one may predict through simulation which outdoor spaces would tend to be more comfortable than others for sedentary activities, within the Buenos Aires climatic context. It is clear that there is no such thing as an optimal combination for any period. Therefore, it is argued that the approach to achieving outdoor comfort should not focus on providing one ideal sensation, but rather offer several within close walking distances. The correct approach would therefore consist of providing a number of varieties with the appropriate combinations at the times when the outdoors has the highest potential to attract people, allowing the users of these spaces to find their own comfort.

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The Catalyst role of School Architecture in enhancing Children's Environmental Behavior

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ABSTRACT:

The interrelationships between school design and children learning are well established. Less evident is the relationship between sustainable school design and the level of environmental behaviour of the children in attendance. Newly erected primary schools in Australia have been broadly graded as either sustainable or conventional. This paper evaluates the impact of both sustainable and conventional school design on children's environmental behaviour, and examines the correlation between school design and children's environmental behaviour.

624 children, aged 10-12 years old, completed a survey. This sample, from seven selected primary schools in Victoria (Australia), includes four conventional schools and three sustainable ones. The survey was developed according to GEB (General Ecological Behavior) scale and a few more school specific variables.

The outcome of the survey was analyzed using an independent sample t-test and two-way between groups ANOVA in order to assess environmental behavior differences of children in both sustainable and conventional schools taking into account factors that either explicitly and/or implicitly impact on their behavior such as sustainable school design, teachers' environmental behavior and parents' environmental behavior.

The results show statistically significant differences in environmental behavior of children in sustainable schools and those in conventional schools. Comparing the means of children's environmental behavior indicates that children in sustainable schools posses higher levels of pro-environmental behavior than children in conventional schools.

The paper highlights the strong relationships between school design and children's environmental behavior, and expands recognition of the role of environmentally sensitive school design not only to improve learning environments but more specifically to engage children ecologically with their immediate built environment.

Keywords: Sustainable School Design; Environmental Behavior; Children

INTRODUCTION

According to the present status of the environmental challenges across Australia, it is essential to take more serious measures to deal with the upcoming hazards of the environmental issues. In order to

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address this, environmentalists have used several different approaches which are categorized into two groups of direct approach and mediated approach. Direct approaches are those measures affecting the status of the environment directly. An example is controlling the amount of carbon emission into the atmosphere. Mediated approach though is those measures that effectively impact the status of the environment through the mediated role of another agent. An example is to enhance the people's literacy through environmental education which mediates people's environmental attitude and behavior. The focus of this paper will be on the mediated approach of environmental education for children through the sustainable school design.

LITERATURE

Children and Environment

Environmental sustainability has become a major social issue in the present century(Wilson & Knopt, 2002). Since environmental sustainability is largely about human choices and actions, each individual has a lot to contribute toward change of environmental behavior. The change toward more sustainable environment involves the societal groups in different levels. Children's role as one of these levels becomes of special interest, and assisting each child to obtain more comprehensive understanding of the environment becomes crucial.

Environmental Education

Public concern about the environment peaked in 1991(Roberts & Bacon, 1997). Emergence of the environmental consciousness has encouraged programs of environmental education around the world in recent decades. Lucas (1972) categorized programs of environmental education into three classes; *Education about the environment*: facts, concepts, principals; *Education for the environment*: attitude and skills directed to conservation; *Education in the environment*: forms of outdoor education. "Learning about the environment supports environmental understanding and knowledge; Learning for the environment is directed toward environmental stewardship and action; Learning in the environment encourages interactions and experiences in the environment" (Disinger, 1990; Murdoch, 1993). All the three mentioned dimensions should be accessible through schooling in order to provide a comprehensive approach to children's environmental learning (Malone & Tranter, 2003).

Different environmental education programs and initiatives vary in their specific goals, but there is usually a typical outcome for most of the EE and that is to enhance participants environmental knowledge, attitude, and behavior(Borden & Schettino, 1979; Hungerford & Volk, 1990; F.C. Leeming, Dwyer, & Bracken, 1995; Musser & Malkus, 1994; Stern, Powell, & Ardoin, 2008).

The most popular and conventional method for environmental education has been through curriculum development. In Australia, despite the shift towards centralization of control over curriculum and development of national curriculum(Palmer, 2002), there is still no unified national scale environmental curriculum. There are also many states which does not have a cohesive curriculum within the state and prefer to have a teacher's oriented and school-oriented environmental education.

Other environmental education efforts have focused on environmental initiative or programs such as field trips or outdoor activities, and investigated the indirect impact of these programs on children's environmental awareness. The third method for environmental education is through applications in the built environment. The later approach seeks assistance from the built environment to transfer and translate some of the environmental concepts to the occupants of the space whether indoor or outdoor.

Although there have been a large number of research about the relationship between the school physical environment and educational outcome(Clark, 2002; Earthman, 1998; Leiringer & Cardellino, 2011; Woolner, Hall, Higgins, McCaughey, & Wall, 2007), there are few research on the impact of the school built environment on children's environmental awareness; the focus of this paper.

School Physical Environment and Children's Behaviour change

Alongside the effective role of the school physical environment on children's educational outcome, designed environment has the potential to form its occupants' behavior, governs and supports interactions between people. This behavior change is in fact part of the desired outcome of environmental education if the environmental behavior is meant.

There is considerable evidence regarding the relationship between students' and teachers' behavior and attitude and their school physical settings (Day, 2007; Durán-Narucki, 2008; Moore, Lackney, Wisconsin Univ, & Urban, 1994). Schools physical environment transmit symbolic messages to children(Proshansky & Wolfe, 1974). Some of the spatial setting encourage and facilitate some of the behaviors while others might hinder and inhibit some behaviors. As a method to test the hypothesis that spatial changes in school environment could generate desirable changes in student's behavior, Weinstein(1977) recorded the activities and locations of the students on the floor plan of the rooms. She found that, in most cases, the desired and predicted behavior of students was attained. The behaviors observed could be social, physical or technical skills(Wilks, 2010). As such, school built environment is central not marginal to student's behavior and performance(Department for Education and Employment, 2001). Even minor changes in physical settings of the school have been reported as an effective factor to generate desirable changes in children's behavior. Weinstein investigated the spatial distribution of the 2nd and 3rd grade students' activities in open classrooms in two stages: before and after some changes in physical design. She found statistically significant differences in students' behavior between the two stages. Changing the spatial design of the classes encouraged students to move into the spots of the class which was previously avoided, and resulted in altering the frequency of specific behaviors(Weinstein, 1977).

Environmental Behaviour

Environmental behavior is defined as the "actions which contribute towards environmental preservation and/or conservation"(Axelrod & Lehman, 1993, p. 153). Humanity might not be able to solve the current environmental problems, but at least through more positive environmental behaviors, we can prevent further failure. Due to the importance of the individual's action towards the environment, one of the clear goals of environmental education is to improve environmental behavior(Pooley & O'Connor, 2000) which ultimately determine the wellbeing of human being. Individual's environmental behavior and the impact people have on the environment have attracted public concern and have motivated large number of environmental and psychological research. Consequently, the volume of research devoted to environmental behavior has proliferated over the last four decades, and researchers have concluded that behavior change is necessary to preserve environmental quality(Frank C. Leeming, Dwyer, & Porter, 1993).

Sustainable School as a Catalyst to Encourage Environmental Behaviour

There has been emphasis in the literature for the role of the built environment on behavioral change. School buildings and design have however rarely been considered as the tool for environmental education and environmental behavior change for children. In recent decades, environmental education has evolved significantly. The issue whether EE should be presented in the form of a separate course at schools or should a trans-disciplinary approach be used is now being questioned. Although teaching through curriculum continues to be a major method for EE, other less directly observable and more implicit methods such as learning through participation (hands on experiences) or learning through knowing eye (visual literacy) have also been developed. Children spend the most fruitful hours of their daylong at the school environment. If the school environment is sustainably designed, this long period of exposure could positively influence children's environmental attitude. It can act as the three dimensional text book or silent curriculum which might not be palpable, but effectively impact on positive or negative learning experiences of users of the space. Architects should therefore provide design for schools that not only generate and facilitate visual literacy, but also reveal environmental messages through school buildings and spaces.

This paper investigates the impact of the sustainably designed schools, as an indirect teaching tool, on enhancing children's pro-environmental behavior. The paper measures the environmental behavior of children in two different types of schools to investigate whether there is any significant difference between the two.

METHODS

The paper identifies 3sustainably designed schools and 4 Conventional ones in Victoria, Australia. A slightly modified version of General Ecological Behavior (GEB) framework is applied to assess general environmental behavior of children, their parents and teachers in the two designated type of schools. Based on the measurement of the environmental behavior of teachers and parents, the paper proceeds to investigate the relationship between children's environmental behavior and the three potential effective factors of school design, teacher's environmental behavior and parent's environmental behavior. The survey can be found in the appendix.

Selecting Criteria of Sustainable versus Conventional Primary Schools

Sustainably designed schools were selected through *ResourceSmartAuSSI Vic*; an Australian Sustainable School Initiative in Victoria that aims to support schools and their communities to live sustainably. *ResourceSmartAuSSI Vic* is managed by Sustainability Victoria in partnership with the *Department of Education and Early Childhood Development* (DEECD). "This framework aims to help Victorian schools minimize waste, save energy and water, promote biodiversity, and cut their greenhouse gas emissions"(Victoria, 2013). Victorian government has been supporting the schools to attend this initiative and continue their sustainability activities. This overarching framework defines 5 levels as 5 stars for schools, so schools should pass the first 4 level to be awarded the 5 star certificates which is the most reliable and valuable certificate for sustainable schools. 5Star gives schools the opportunity to show continuous improvement in their environmental performance through the five levels. Therefore, based on ResourceSmartAuSSI Vic 5-star certificate, St Macartan's, Epping view, and Gembrook primary schools have been chosen as the sustainable schools and Geelong East, Rollin's, Belmont and St Patrick's Primary Schools have also been chosen as conventional schools. All these primary schools were public schools and located in Victoria State. Some of the common features and characteristics of the sustainable school buildings include:

- Passive design of the school building, such as appropriate orientation of the building to utilize natural sources of heating and cooling as much as possible; and careful design of the school building envelope (roof, walls, windows, etc.)
- Water tanks in order to store rainwater for flushing the school toilets and also watering the school garden
- Solar panels in order to provide electricity
- Worm farms
- Compost bins
- Well-designed outdoor environment and landscape

Participants

Participants from 7 primary schools in Victoria, Australia were classified in three categories; children, their parents and their teachers.

Children

The children participants included 624 students from 7 primary schools, of which 387 children were from sustainable and 237 from conventional schools. The total number of the students in grade 4, grade 5, and grade 6 were respectively 244, 169, and 211.

Table1

Children

	CONVENTIONAL SCHOOLS				SUSTAINABLE SCHOOLS		
	GEELONG EAST	ROLLIN'S	BELMONT	ST PATRICK'S	ST MACARTAN'S	EPPING VIEW	GEMBROOK
N	27	33	34	143	86	230	71
TOTAL			237			387	

Teachers and parents

Since teacher's concern about environmental issues is one of the potential external factors affecting children's environmental attitude and behavior, teachers of the same students who attended were one of the groups of participants. 42 teachers from 7 primary schools were asked to fill out a questionnaire containing the GEB items. This questionnaire was used to assess the environmental behavior of teachers who are in direct contact with children every day in the classroom environment.

Table 2

Teachers

	CONVENTIONAL SCHOOLS				SUSTAINABLE SCHOOLS		
	GEELONG EAST	ROLLIN'S	BELMONT	ST PATRICK'S	ST MACARTAN'S	EPPING VIEW	GEMBROOK
N	3	5	6	7	10	7	4
TOTAL			21			21	

Since parent's environmental attitude and behavior level can be another factor impacting children's environmental awareness, the researchers collected data from the parents whose children attended the survey to further investigate the association between the two. Not all of the children returned their corresponding parent's questionnaire. Parent's sample size was almost 35% of the population of the children. A quite noticeable discrepancy in gender response rate was observed. In total 77% of the parents respondents were females and 23% were males. This could be because females care more about environment or they are less busy than males to respond the questionnaire.

Table 3

Parents

	CONVENTIONAL SCHOOLS				SUSTAINABLE SCHOOLS		
	GEELONG EAST	ROLLIN'S	BELMONT	ST PATRICK'S	ST MACARTAN'S	EPPING VIEW	GEMBROOK
N	20	31	31	-	71	50	14
TOTAL			82			135	

Table 4. Participants of 3 groups (Children, Parents, and teachers) of this study

	TYPE OF THE SCHOOL DESIGN	NO. OF THE CHILDREN PARTICIPANTS			NO. OF THE PARENTS PARTICIPANTS			NO. OF THE TEACHER PARTICIPANTS		
		FEMALE	MALE	TOTAL	FEMALE	MALE	TOTAL	FEMALE	MALE	TOTAL
GEELONG EAST	CONVENTIONAL	15	12	27	17	3	20	3	0	3
ROLLIN'S	CONVENTIONAL	20	13	33	25	6	31	4	1	5
BELMONT	CONVENTIONAL	23	11	34	23	8	31	4	2	6
ST MACARTAN'S	SUSTAINABLE	47	39	86	55	16	71	9	1	10
EPPING VIEW	SUSTAINABLE	119	111	230	38	12	50	4	3	7
GEMBROOK	SUSTAINABLE	34	37	71	10	4	14	3	1	4
ST PATRICK'S	CONVENTIONAL	79	64	143	0	0	0	4	3	7
TOTAL OF EACH GENDER		337	287	624	168	49	217	31	11	42

Data Collection

Parent's plain language statement, consent forms, and questionnaire were provided 2-3 weeks before going to the school for the data collection. Children's were asked to take the forms to their homes and ask their parents to study the plain language statement which was a brief description of the project, sign the consent form if they are happy for their children to participate in the survey, and answer the questionnaire. Children were encouraged to return the parent's questionnaire at the day of the data collection. Although the teachers emphasized students to bring back the parent's questionnaire, not all of them returned the forms.

In schools, the researcher allocated 45 minutes for each set of data collection. Data was collected from maximum 50 students each time. After a couple of tests (practices), it was found that this number is an appropriate number in each set, as one would not be able to control more number of the primary school children at once, even with the teachers supervision. In each school, at least one of the teachers assisted and supervised the children and encouraged them to answer the questions.

Before administering the survey, the researchers ensured that all children understood that the collected data is anonymous and the child could terminate attending the survey at any time without any consequences. Children were also asked to feel free to request more explanation if any question is not clear enough.

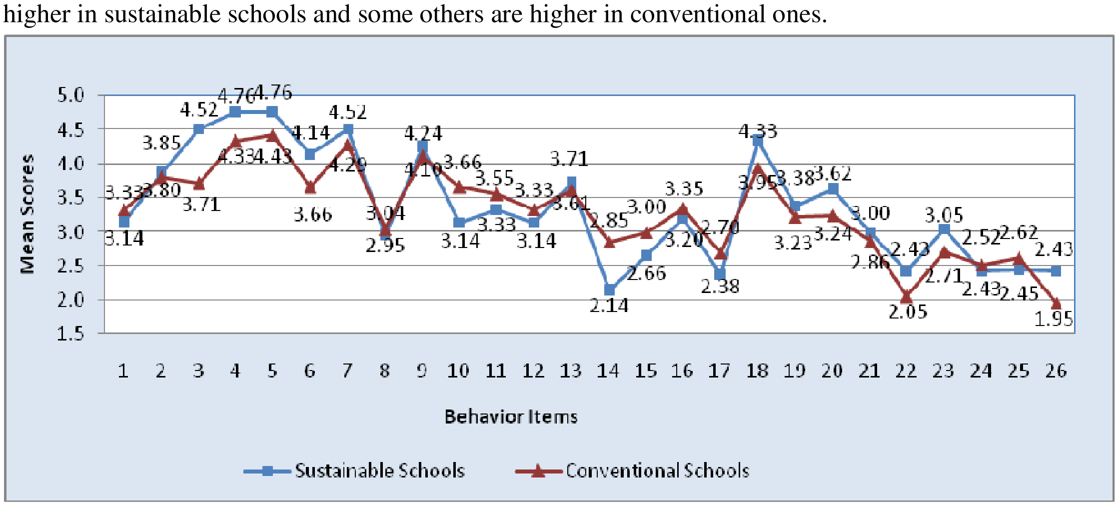
ANALYSIS

To evaluate the impact of sustainable school architecture on children's environmental behavior, potential influential variables were taken into account. To measure the impact of the school design, factors such as curriculum, teachers' and parents' environmental awareness were considered. Research shows that although almost all primary schools in Victoria include some environmental education in their educational system, they don't have a mandatory and pre-defined curriculum. Each school has developed its own unique environmental behavior curriculum. As such, no two schools environmental curriculum was alike, and controlling the impact of curriculum was not completely achievable in this study. Teachers' environmental behavior was compared in two different types of school in order to investigate any differences. The environmental behavior of parents whose children attend sustainable schools and those whose children are at conventional schools were also examined. After careful investigation and obtaining a comprehensive knowledge about the impact of these two factors, further analysis is preceded continued on children questionnaire?

Teachers' Environmental Behavior Differences in Sustainable and Conventional Schools

The impact of teacher's environmental behavior on children's environmental behavior is of great importance regarding to opportunities teachers provide for environmental education of children at schools. Teacher's environmental behavior level is measured with GEB measure.

Graph 1 shows the mean differences of all teachers' environmental behavior of both sustainable (Blue line), and conventional (Red line) schools. It indicates that some of the behavior means scores are higher in sustainable schools and some others are higher in conventional ones.



Graph 1: Teachers' Environmental Behavior at Sustainable and Conventional Primary Schools

An independent sample t-test was conducted on 42 teachers (11 male, and 31 female), in order to find out whether any of these environmental behavior differences between the sustainable schools and conventional schools are significant. Teachers' environmental behavior is considered as the continuous dependent variable and type of the school design (Sustainable/ Conventional) is considered as the categorical independent variable.

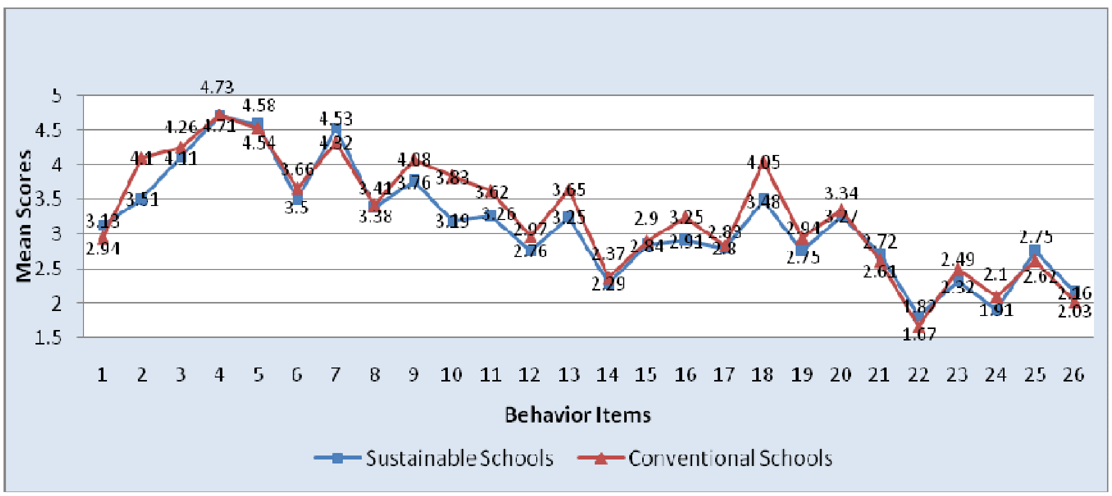
Output of the t-test shows that magnitude of the differences in the means (mean difference= .066, 95% Cl: .344 to .476) shown on the graph are very small (eta squared=0.002), and not significant for teachers in sustainable primary schools (M= 3.37, SD=.287) and teachers in conventional primary schools (M= 3.31, SD=.865; t (24.3) = .332, p=.74, two-tailed).

Consequently, the results show that teacher's environmental behavior was not significantly different in the two types of schools, ignoring the impact that teachers' environmental behavior might have on children. The research continues to examine other factors affecting children's environmental behavior including parent's environmental behavior and school design.

Parents' Environmental Behavior Differences in Sustainable and Conventional Schools

To understand if the parent's environmental attitude and behavior should be included in analysis as one of the factors affecting children's environmental behavior, several investigations are carried out. Out of 624 questionnaires which were sent to students' houses, 259 parents (~ %41) responded of which 114 parents belonged to sustainable schools and 145 belonged to conventional schools.

Graph 2 shows the environmental behavior mean scores of all parent participants for each of the questionnaire item in sustainable (Blue line) and conventional (Red line). Since the graph shows the slightly different mean scores for two types of schools, a t-test in conducted to verify the magnitude of this difference.



Graph 2: Parents' Environmental Behavior at Sustainable and Conventional Primary Schools

Output of the t-test divulge that there is a significant difference in the behavior mean scores of parents in sustainable schools (M= 3.143, SD=.383) and parents in conventional schools (M= 3.282, SD=.371; t (257) = 2.937, p=.004, two-tailed). However, the magnitude of the difference in the behavior mean scores (mean difference= .138, 95% Cl: .231 to .045) was small (eta squared= .032). According to eta squared, although there might be no practical significance between the mean score of parents in conventional schools and means scores of parents in sustainable schools, but interestingly this little difference is in favor of the parents of conventional schools. Therefore, researchers could not overlook the possible impact of parents' environmental behavior on children's environmental behavior and included this factor alongside the school design factor for further analysis.

Children's Environmental Behavior Differences in Sustainable and Conventional Schools

Two-way between groups ANOVA is conducted to explore the impact of parents' environmental behavior and sustainable school design on children's environmental behavior as measured by the Life Orientation Test (LOT). This analyzing technique gives the researchers the opportunity to look at the individual and joint effect of two mentioned independent variables on children's environmental behavior as the dependent variable. The '*main effect'* for each independent variable is tested and also the possibility of an *'interaction effect'* is explored (Pallant, 2013).Two-way between groups ANOVA answers the following questions:

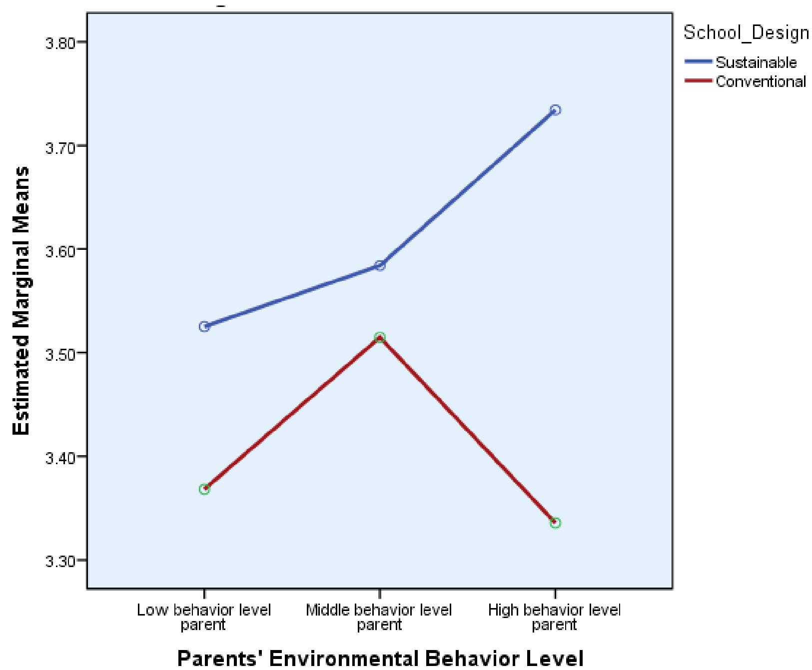
-What is the impact of parent's environmental behavior and sustainable school design on children's environmental behavior?

-Whether parents' environmental behavior moderates the relationship between the school design and children's environmental behavior?

209 parents out of total number of 259 parents were entered to this part of analysis. Those 50 parents' data could not be matched with their corresponding children and therefore, have been taken out of analysis. Parents' data were categorized into three groups according to their environmental behavior mean scores.Group1 were called *Low Enviro-Behavior Level Parents* and they were parents with overall behavior mean of less than 3.10 (N= 78). The second group of parents, who were *Middle Enviro-Behavior Level Parents*, was those who possessed overall behavior mean between or equal 3.10 and 3.35(N=59). *High Enviro-Behavior Level Parents* were those who had overall behavior mean of more than 3.35(N=67). These parents' data were entered to ANOVA test alongside with their corresponding children. Therefore just 209 children's data out of 624 children was used in this analysis.

The sig. = 0.27 for *Levene's Test of Equality of Error Variances* suggests that the homogeneity of variances assumption have not been violated ($p>.05$). The output of the two ways ANOVA indicates that the interaction effect between the school design and parents' environmental behavior level was not statistically significant, $F(2,203)=1.38$, $p=.254$, meaning that the influence of sustainable school design on children's environmental behavior does not depend on their parents' level of environmental behavior. An alternative interpretation could be the influence of parents' environmental behavior level on children's environmental behavior does not depend on whether they attend sustainable school or conventional school. Further analysis in this paper will indicate if there is any significant influence (main effect) of each of these independent variables on children's environmental behavior at all. Output shows that no statistically significant main effect was found for parent's environmental behavior level on children's environmental behavior $F(2,203)=.581$, $p=.56$. This means that overall, when we ignore the type of the school design; parents' environmental behavior level does not influence children's environmental behavior level. Other factors being equal, children with any parental environmental behavior level, posses similar level of environmental behavior. Analysis has also revealed that there is a statistically significant main effect for school design $F(1,203)=6.10$, $p=.014$; however, the effect size was not large (partial eta squared=.029).

Graph 3 shows the children's environmental behavior mean scores for sustainable schools and conventional schools, across the three parents' environmental behavior level category. It appears that the largest difference in children's environmental behavior between the sustainable and conventional schools occurs when children have parents with high level of environmental behavior. The analysis also demonstrates that children in sustainable schools and conventional schools possess the most similar level of environmental behavior when their parents have middle level of environmental behavior; however analysis showed that these differences were not significant. Graph 3 also depicts the difference between the environmental behavior of children in sustainable schools and conventional schools. According to this graph generally children in sustainable schools behave more pro-environmental than the children in conventional schools.



Graph 3: Interaction of school design and parents' environmental behavior level in children's environmental behavior

DISCUSSION AND CONCLUSION

Considerable amount of information concerning the impact of school design, school architecture, or school physical environment on children's attitude, behavior, or academic achievements has been addressed through literature. There is a growing body of literature regarding the advantages of attending sustainable schools. There seems to be a gap between these two fields of research and the impact of sustainable school design on children's environmental behavior. This paper compares the environmental behavior of children in sustainable schools and conventional schools considering the environmental behavioral levels of both teachers and parents. GEB measure for both children and adults was employed. Few supplementary questions were added to make it appropriate in an Australian context. 624 children, aged 10-12 years old from seven different primary schools in Victoria State (three sustainable and four conventional), 42 teachers and 209 parents completed the survey. Only 209 out of 624 children's data was usable to analyze the differences between the environmental behavior level of children in sustainable schools and conventional schools. A t-test showed that there is no significant difference between the environmental behavior of teachers in sustainable schools and conventional schools, and as such teacher's environmental behavior as one of the potential factors affecting children's environmental behavior could be overlooked. This was not the case for parents though. Another t-test indicated that there is a significant difference between the environmental behavior of parents in sustainable schools and conventional schools. Therefore, at a secondary level of analysis, a two-way ANOVA was conducted to investigate the role of both parents' environmental behavior and school design on children's environmental behavior. A number of conclusions were drawn. First, there is no statistically significant interaction between parent's environmental behavior and school design, and so the effect of parents' environmental behavior on children's environmental behavior shows no difference in sustainable schools and conventional schools. The impact of school design on children's environmental behavior does not depend on their parents' environmental behavior level. This result paved the way to investigate the effect of sustainable school design on children's environmental behavior with the isolation of parents' and teachers' influence.

Second, the results also indicate that there is a significant difference between the environmental behavior mean scores of children in sustainable schools and conventional schools with higher estimated marginal means for sustainable schools. Although, as seen on graph 3 the magnitude of this difference is not large (3.75-3.35), it can support this study hypothesis that sustainably designed primary schools supply some opportunities for improving children's environmental behavior education. This relatively small difference might be an indication of lack of enough attention to, or investment on the sustainability design of primary schools in Victoria State and it performs as a warning to inform the decision makers and educationalists to strengthen the existing correlation between the sustainable primary school environment and children, and to foster children with environmental friendly behavior through the indirect teaching tool of sustainable schools design.

Although factors such as parents and teachers environmental concerns have been taken into consideration in this study, impact of other potential factors such as environmental curriculum of each schools and socio-economic situation of children's family, or the duration of the exposure to the school building needs further investigation. Each of the approached primary schools had their own developed environmental curriculum, and generally there was not a pre-defined, unified, and structured environmental curriculum for all schools to use. Therefore, this lack of consistency hindered the researchers to have a comprehensive control over the presented curriculum at schools.

In conclusion, the relationship between sustainable school design and children's environmental behavior provides further supports for the value of investments on sustainable architecture of school environment and encourages thorough attention of architects, designers, and policy makers in order to develop children pro-environmental awareness and behavior. Further studies are required to apply the methodology to different contexts. The researchers are currently involved in assessing whether the sustainable school features and characteristics can mediate the relationship between children's environmental attitude and children's environmental behavior. In other words, does sustainable school building facilitate converting the environmental attitude to the environmental behavior or action of primary school children?

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CHILDREN'S ENVIRONMENTAL BEHAVIOR MEASURE FOR CHILDREN :
1. I PARTICIPATE IN RECYCLING ACTIVITIES AT SCHOOL. **2. I WORK IN THE SCHOOL GARDEN WITH TEACHERS.** **3. I DO NOT FORGET TO TURN LIGHTS OFF WHEN I LEAVE A CLASSROOM.** **4. I PICK UP LITTER LEFT BEHIND BY MY FRIENDS DURING RECESS AND LUNCH BREAKS.** **5. I DO NOT FORGET TO TURN OFF WATER AFTER WASHING MY HANDS IN THE SCHOOL TOILETS.** **6. I DO NOT BRING TOO MUCH FOOD TO SCHOOL AND I HAVE TO THROW AWAY THE EXTRA FOOD.** **7. I LOOK AT BOOKS ABOUT THE ENVIRONMENT (NATURE, TREES, AND ANIMALS).** **8. I DO NOT LEAVE THE CLASS WINDOW OPEN WHILE THE HEATER IS WORKING.** **9. I DO NOT TURN ON THE AIR CONDITIONER RATHER THAN OPENING THE**

GLASS WINDOW WHEN IT IS WARM INSIDE.

10. **I DON'T TURN ON THE CLASSROOM LIGHTS BECAUSE THERE IS ALWAYS ENOUGH LIGHT IN MY CLASSROOM.**

Session 4D : Tools and methods/ framework

PLEA2014: Day 2, Wednesday, December 17
8:30 - 10:10, Trust - Knowledge Consortium of Gujarat

A new subjective-objective approach to evaluating lighting quality: A case study of concert lighting for Cambridge King's College Chapel

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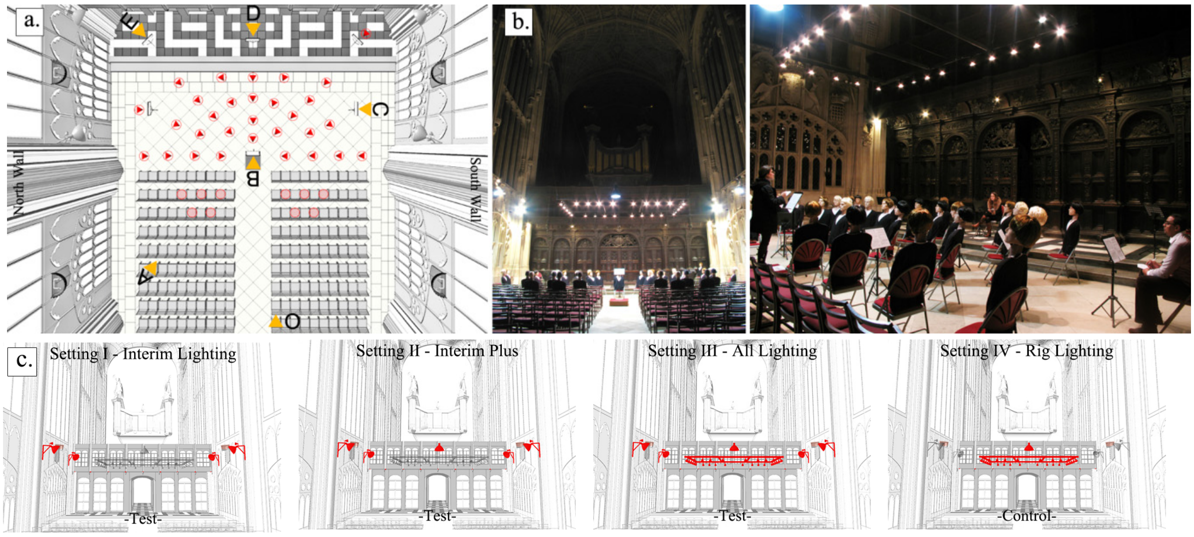
ABSTRACT

Drawing on theoretical insights from acoustic research, this paper presents a subjective-objective method that complements and unifies existing approaches to assessing lighting quality. In essence, the method establishes numerical relationships between subjective attributes and objective lighting measures, the applicability of which is demonstrated through a comparative study of four different concert light settings in Cambridge King's College Chapel. A total of 624 subjective responses were collected from a full-scale experiment. These focused on seven subjective aspects: visual clarity, visual balance, visual uniformity, brightness, spatial intimacy, appropriateness/comfort, and overall impression of the luminous environment. Variations in the response were analysed systematically and correlated with 22 objective attributes, which were computed using luminance and photometric data extracted from High Dynamic Range images. This study reveals significant connections between the selected subjective parameters and the objective attributes that are used to describe a visual scene mathematically and spatially.

Keywords: Lighting Quality, Objective Measure, Subjective Judgment, High Dynamic Range Imaging

INTRODUCTION

Despite the growing awareness of the need to create a sensible lit environment and to develop appropriate lighting systems to reduce energy use, there is currently little consensus on the way we evaluate lighting quality in relation to its quantity. This is a complex subject, in part because lighting perception is often influenced by non-quantifiable human factors. To be able to characterise lighting quality accurately, it is important to gain an understanding of the connection between seeing and perceiving. In the past, several attempts (Flynn *et al.*, 1979; Loe *et al.*, 1994, Moore *et al.*, 2003) have been made to explore this subjective-objective connection, yet little has been established about its framework and applicability. In this paper, drawing an analogy between acoustics (Beranek, 1962; Barron, 1988; Barron, 1993) and lighting research, we develop an analytical framework based on the acoustics' numerical framework — one that studies what perceptual attributes contribute to the overall listening experience in concert halls — and we test this framework in order to analyse concert lighting for Cambridge King's College Chapel. In the literature, the majority of lighting studies have focused on contemporary spaces such as offices, schools and museums (Newsham *et al.*, 2001; Wymelenberg *et al.*, 2014). In this sense, our study is unique in that it examines the effects of light in a historic context. Our aim is to present and apply the subjective-objective framework to study lighting quality. First, we describe the experimental set-up, including the procedure through which our subjective and objective data were collected. We then identify the key attributes that influence lighting impression and the relationships among them, followed by the key findings. Finally, we discuss the strengths and limitations of this study.



- 4 x 320w fluorescent lamps
- 8 x 16w supplementary spot light units

- Combination of Setting I and 1 x 320w overhead fluorescent lamp

- Combination of Setting I and Setting IV

- 1 x 320w fluorescent lamp
- 28 x 75w spot light units mounted to a steel rig structure

Figure 1 [a] King's College Antechapel: Plan arrangement[‡], [b] Experimental scene, [c] Schematic illustration and description[‡] of the four light settings ([‡] Lo & Steemers, 2014)

EXPERIMENTAL PROCEDURE AND DATA COLLECTION

Working with historic buildings poses practical and logistical challenges, especially when it comes to collecting objective data and conducting field experiments. For fidelity, we reconstructed a concert environment with the use of dummies (Lo & Steemers, 2014) (Figures 1a and 1b). While peripheral lighting for the walls and the wooden screen were switched on in all tests, luminance, spot luminance and illuminance were measured under four artificial light settings (Figure 1c): Setting I (Interim Lighting), Setting II (Interim Plus), Setting III (All Lighting) and Setting IV (Rig Lighting). The visual fields of occupants were captured with a fish-eye lens at six locations (Spots O and A = audience members; Spot B = conductor; Spots C, D and E = musicians) (Figure 1a), resulting in a total of 24 visual scenarios.

All the images were generated using High Dynamic Range (HDR) photography. Each HDR image was calibrated against physical luminance measurements taken with a Minolta LS-100 Luminance meter and was generated in Radiance by merging 15 multiple-exposure RAW images. With a fixed aperture of f/5, these images were taken with exposure times ranging from 1/1000s to 15s. The photometric data and images were then processed in Matlab and analysed in relation to the structure of our visual field, providing a comprehensive mathematical and spatial analysis of light for the antechapel (Lo & Steemers, 2014). Through the use of these techniques and classical principles of quantifying light, 22 equations were derived from the images to evaluate visual acuity, luminance contrast, uniformity, variation, perceived brightness and contrast, relative luminance, visual boundary and light patches for all the scenarios. Subjective data were collected through a highly structured field experiment and questionnaires.

Seventy-eight university students and staff members volunteered to participate in the experiment. Twenty-six responses were collected at each spot. The participants were asked to imagine themselves attending or performing in an orchestral and chorus concert of religious music, and each was assigned to a specific spot. Upon completion, they were assigned to another spot with a different visual field and were asked to repeat the task. They were also instructed to compare Settings I, II and III with Setting IV (i.e. the control) and to make objective and subjective judgements accordingly. To avoid possible bias, we randomised the sequence in which the settings were presented. For each setting, the participants had to fill in a one-page questionnaire, which was organised into three main sections — i) Visual clarity, ii) Distribution of Light and iii) Spatiality — and concluded with a question concerning the overall lighting impression. Additional space was provided for further comments. The subjective questions focused on 1) visual clarity, 2) visual uniformity, 3) visual balance, 4) brightness, 5) spatial intimacy, and 6) appropriateness/comfort. The ratings for these were given on a seven-point Likert scale. Unlike other

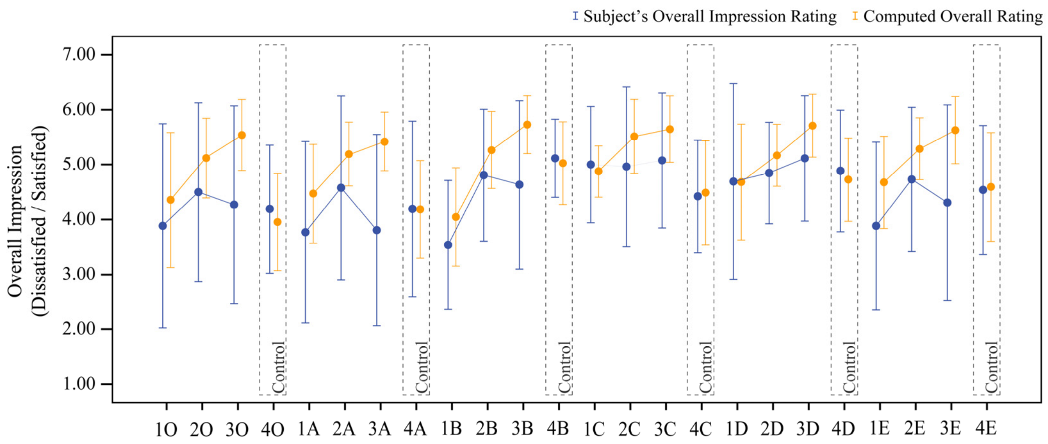


Figure 2 Overall impression rating and computed overall rating for each setting and position

lighting studies, which relied on semantic differential scales (Flynn *et al.*, 1973; Hawkes *et al.*, 1979; Loe *et al.* 1994), our questionnaire was a combination of factual, semi-subjective and subjective questions, which enabled us to justify the responses. For visual clarity, for example, we asked the audience participants '*how well can you read the programme and see the facial expressions of the musicians*' along with the Hazy/Clear scale. Other semantic differential scales used in this study were Non-uniform/ Uniform, Inappropriate/Appropriate, Dim/Bright, Confined/Public and Uncomfortable/Comfortable. More details on the experimental set-up and questionnaire design are available in Lo & Steemers (2014).

ANALYTICAL METHOD, FINDINGS AND DISCUSSION

Validation of the experimental technique

The experimental technique was validated i) by comparing the overall impression rating obtained from the concluding question — '*How satisfied are you with the overall lighting experience?'*— with ratings computed by averaging the sum of the average scores derived from the three main sections; ii) by examining whether the structure of the experimental design had an effect on the overall impression; and iii) by identifying whether there were significant differences among the scores of each question.

i. The changes in the rated and computed impression scores follow a similar pattern, except in the case of Setting III where a divergence is observed (Figure 2). Results from a T-test, performed without assuming equal variances, indicate that there is a significant difference between the scores at Spot O (t (31.40) = -3.39, $\rho < .01$), Spot A (t (29.69) = -4.51, $\rho < .01$), Spot B (t (30.87) = -3.45, $\rho < .01$) and Spot E (t (30.84) = -3.57, $\rho < .01$). Their mean values show that the computed scores ($\bar{x}_O$= 5.54; $\bar{x}_A$= 5.42; $\bar{x}_B$= 5.73; $\bar{x}_E$= 5.63) were significantly higher than the rated scores ($\bar{x}_O$= 4.27; $\bar{x}_A$= 3.81; $\bar{x}_B$= 4.63; $\bar{x}_E$= 4.31). This implies that although the factual questions and Dim/Bright scale received higher scores, the participants felt uncomfortable and tense in some cases because of the brightly lit environment, and had an undesired impression as a result. This is also evident in their comments, as one said, '*By far the least comfortable lighting of all. It's very stressful for the eyes.'* (Spot A: Rated score = 1; Computed score = 5.22)

ii. Results from ordinal regression indicate that the order of the experimental session was not significantly associated with the tendency of response (*Sig.* =.279). In addition, there is no consistent agreement in the standard deviation of the scores observed between the first and second sessions. We therefore reject the hypothesis that the experimental structure affected the overall impression.

iii. A one-way Kruskal-Wallis analysis of variance test was used to analyse the ratings for all the scenarios, and post-hoc tests were performed to pinpoint the differences. The broadest consensus among the responses is observed at all the positions in Setting III. Significant differences, however, were detected between the factual and subjective questions in the section on 'Distribution of Light', as well as in the section on 'Spatiality' between the scales of Inappropriate/Appropriate, Dim/Bright and Uncomfortable/ Comfortable. Somewhat surprisingly, the participants tended to give lower ratings to the subjective questions when details of architectural features could be clearly seen.

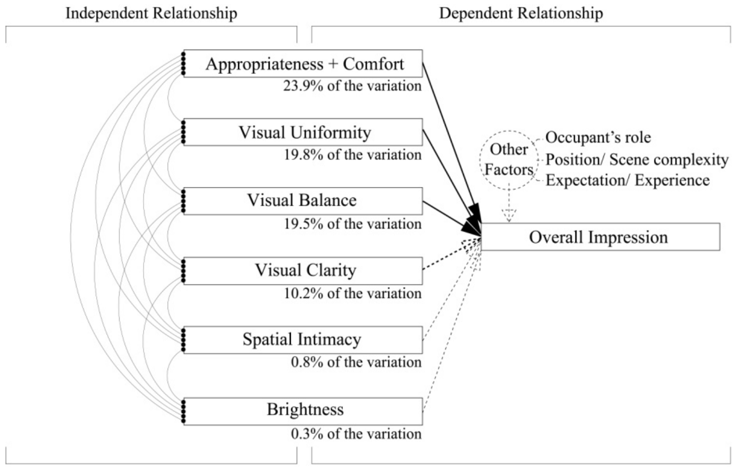


Figure 3 A path model summarising the independent relationship between each subjective variable and dependent relationship with the overall impression.

Correlation between subjective and objective attributes

Next, we grouped the factual and subjective questions in accordance with our subjective attributes, whose internal reliabilities were assessed by Cronbach's alpha. Pearson correlation coefficients were calculated to examine the independent relationship between the attributes. The results are in good agreement with significant results obtained for all the attributes ($\rho < .001$). The correlation matrix reveals that visual clarity, visual uniformity, visual balance and appropriateness/comfort account, respectively, for 10.24%, 26.73%, 46.10%, and 72.76% of the variability in the overall impression, while brightness and spatial intimacy account for 4.12% and 2.02%.

A multiple regression analysis was performed to test the dependence of the attributes on the overall impression. The results show that the regression model is statistically significant ($\rho < .001$), with approximately 74.5% of the variability of the overall impression accounted for by the subjective attributes ($r^2 = 0.745$). The unexplained variation may be attributed to the occupant's role, viewing position, expectation and experience (Lo & Steemers, 2014). The regression coefficients suggest that visual balance, visual uniformity and appropriateness/comfort are significant predictors of the overall lighting impression ($\rho < .01$). However, there is no statistically significant linear dependence of visual clarity, brightness and spatial intimacy on the overall impression. This suggests that the significant predictors have direct influences on the overall impression, while the insignificant predictors have indirect influences.

The predictors were entered into the model in the following sequence: visual clarity, visual uniformity, visual balance, brightness, spatial intimacy and appropriateness/comfort. The change in R-Square shows that visual uniformity explains 19.8% more of the variance in the overall impression than visual clarity (10.2%) does alone, and that visual balance (19.5%), brightness (0.3%), spatial intimacy (0.8%) and appropriateness/comfort (23.9%) further explain the variability. The analyses indicate that appropriateness/comfort was the most important subjective attribute (Figure 3), while brightness was the least important, which suggests that the participants prioritised their needs subconsciously such that the exact brightness level was not pertinent to the overall impression.

The five most significant objective measures: Univariate Linear Regression Analysis

The Pearson correlation of the subjective attributes and objective measures were computed. Because of the large number of correlation coefficients, the following steps were used to categorise the objective measures: i) ranked the five most significant measures; ii) identified the core measures that are common to all the subjective attributes; and iii) identified additional measures that were selected in step one but were not common to all the subjective attributes. Among 154 correlation tests, 84 were reported as highly significant ($\rho < .01$) and 13 were regarded as statistically significant ($\rho < .05$) (Lo & Steemers, 2014). As Figure 4 shows, L_{avg}, RIM_{whole}, $RISD_{whole}$, RL_{std}, Light to Dark ratio (L:D), RL_{avg} and Total area of light patches ($Area_{Light\ patches}$) are the core measures, while L_{std}, Perimeter and VA_{Sheets} are the additional measures [i] It is interesting to find that L_{avg} is the strongest parameter with which to evaluate visual clarity,

	Objective Measures	Visual Clarity	Visual Uniformity	Visual Balance	Brightness	Spatial Intimacy	Appropriateness + Comfort	Overall Impression
Core Measures	L_{avg}	0.459**(1)	0.212**(1)	0.174**(1)	0.453**(1)	0.405**(1)	0.121**	0.109**
	RIM_{whole}	0.453**(2)	0.166**	0.145**(2)	0.341**(3)	0.267**(3)	0.166**	0.173**(3)
	$RISD_{whole}$	0.429**(3)	0.154**	0.142**(3)	0.355**(2)	0.256**(5)	0.116**	0.133**
	RL_{std}	0.377**(4)	0.193**(4)	0.143**(4)	0.284**	0.242**	0.205**(2)	0.186**(2)
	Light : Dark	0.363**(5)	0.194**(3)	0.119**(5)	0.314**(4)	0.257**(4)	0.202**(3)	0.156**
	RL_{avg}	0.353**	0.196**(2)	0.129**	0.278**	0.237**	0.201**(4)	0.170**(5)
	Total area of light patches	0.349**	0.193**(5)	0.118**	0.280**	0.225**	0.214**(1)	0.171**(4)
Additional	L_{std}	0.211**	0.068	0.081*	0.285**(5)	0.282**(2)	-.0680	-.0550
	Perimeter	0.283**	0.176**	0.077	0.230**	0.176**	0.178**(5)	0.129**
	VA_{Sheets}	0.236**	0.099*	0.076	0.093*	.0340	0.173**	0.192**(1)

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).
Ranking of the objective measures are shown in the bracket.

Figure 4 Correlation matrix between subjective attributes and key objective measures (N =624)

visual uniformity, visual balance, brightness and spatial intimacy, while $Area_{Light\ patches}$ and VA_{Sheets} are the strongest ones for appropriateness/comfort and overall impression, respectively. L:D is the only measure that was ranked as one of the top five for all the subjective attributes except for the overall impression. L_{avg} only accounts for the physical measurements of light, which does not reflect changes in acuity within the visual field, eye movements and the selective nature of the eye. Considering L_{avg} to be a fundamental measure along with other key attributes, however, would be a more robust and thorough approach to making predictions of subjective responses.

To better understand the relationships between the significant measures and subjective attributes, we plotted the subjective ratings against the objective measures in two different ways: a) first as a jittered scatterplot, which was generated with the raw data (N=624), enabling analysis of changes in response in relation to the magnitude of the objective attributes; b) second as a non-jittered scatterplot, which was generated with the total mean score given at each position under each lighting condition (N=24), enabling a more general comparison among different visual scenarios. Furthermore, all the data points were categorised on the basis of the occupant's role in order to highlight differences in response between the audience members, conductor and musicians.

1) Visual Clarity. The correlation between visual clarity and L_{avg} (r = 0.46) is the strongest (Figure 5). An increase in L_{avg} led to an improvement in visual clarity. For low levels of L_{avg}, as is the case for Setting IV, there was a greater variation in the responses regardless of the occupant's role. Interestingly, there is an appreciable difference in the visual clarity ratings between Spot B and Spot E in Setting I, with mean ratings of 4.09 and 5.40, respectively, although the L_{avg} levels are similar. This can be attributed to the apparent differences in RL_{avg}, RL_{std}, L:D and $Area_{Light\ patches}$. Halving the levels of RL_{avg} and RL_{std} as well as quartering the L:D ratio and the area of light patches could potentially lower the total mean rating for visual clarity (Figure 7). The two-level greyscale images (Figure 7) illustrate that there is a striking contrast of spatial hierarchy between Spot B and Spot E. For Spot B, white pixels are mostly clustered in the background. For Spot E, however, white pixels are distributed evenly across the work plane and background, highlighting the essential features of a musician's visual scene.

2) Visual Uniformity and Visual Balance. The ranking of the five most significant measures for visual balance is exactly the same as that for visual clarity, although the correlation coefficients are lower. Using other physical measures is more appropriate for describing these relationships. For visual uniformity and visual balance, an increase in RL_{avg} (r = 0.20) and RIM_{whole} (r = 0.16) respectively resulted in a moderate increase in the mean ratings. The mean ratings of these two attributes were at their highest when RL_{avg} and RIM_{whole} were among the highest of all the settings. In contrast, the attributes received the lowest scores in Setting IV at Spots A, C and E, and in Setting I at Spot B. For Spots O and D, the lowest ratings were observed in Setting I. These are also reflected in the overall rating specifically for Setting I at Spots O and B and for Setting IV at Spot C (Figure 2). This, however, was not the case for Setting IV at Spots A, D

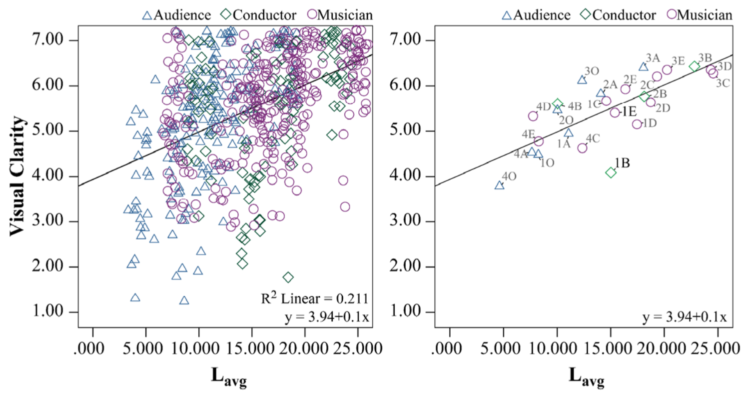


Figure 5 Jittered scatterplot (*left*) and non-jittered scatterplot (*right*) of visual clarity plotted against L_{avg} based on the raw data (N =624) and average ratings (N =24) respectively.

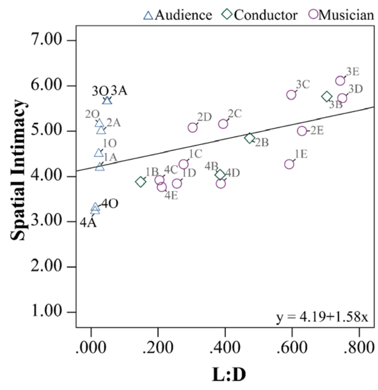


Figure 6 Non-jittered scatterplot: Spatial intimacy plotted against L:D

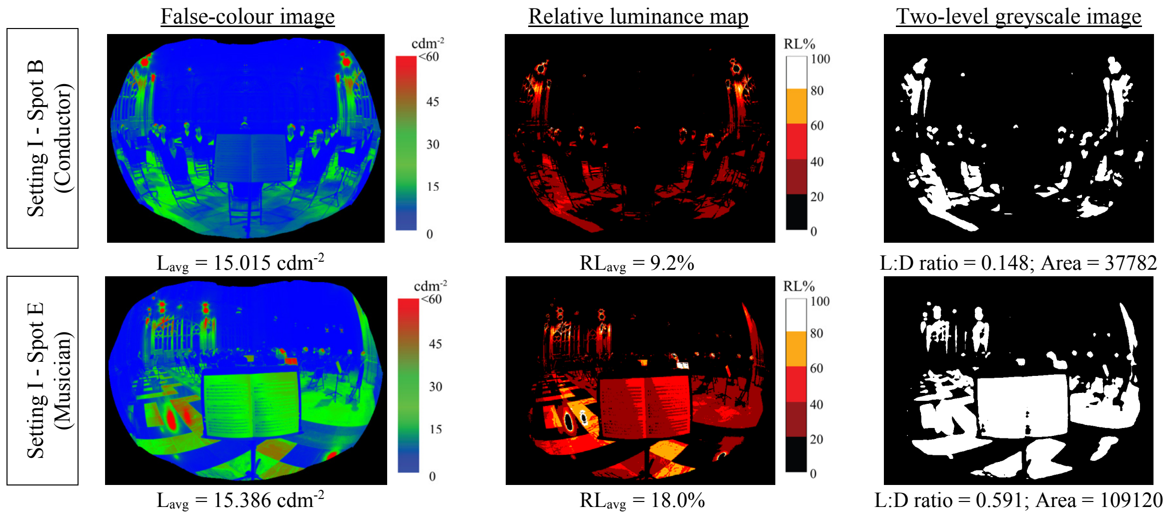


Figure 7 Spatial analysis of light for the antechapel

and E, where the ratings for appropriateness/comfort were comparatively higher. This suggests that by enhancing the appropriateness of the visual environment and visual comfort, it is possible to improve the overall impression despite lower ratings for visual balance and visual uniformity.

3) Brightness and Spatial Intimacy. There was a good correlation (r = 0.36) between brightness and $RISD_{whole}$ — the second most significant measure. With bright sources isolated, this measure refers to the relative brightness contrast of the visual field. Analysis of scatterplots revealed that the audience members' ratings exhibited more scatter than those of the conductor and musicians, suggesting that the agreement for brightness was to some extent related to the occupant's role. This observation also applies to spatial intimacy. As Figure 6 shows, despite its positive correlation (r = 0.26) with L:D, the responses given by the audience members at Spots O and A, where the objective values were very similar, yielded a broader range of scores (min. = 3.23, max. = 5.65) than that given by the conductor and musicians. The lowest and highest mean ratings were observed in Setting IV and Setting III, respectively. In fact, RL_{avg} and RL_{std} Spots O and A were the same in Setting III (RL_{avg} = 4.2%, RL_{std} = 8.9%) and were nearly double those in Setting IV (O: RL_{avg} = 1.9%, RL_{std} = 4.5%; A: RL_{avg} = 1.8%, RL_{std} = 4.6%). Taken together, these findings support the view that the core objective measures are pertinent to the subjective evaluation.

4) Appropriateness/Comfort. Although this attribute contributes the most variability to the overall impression, as discussed above, its correlations with the core objective measures are comparatively weak, indicating that this subjective attribute is difficult to be quantified with physical measures alone. $Area_{Light\ patches}$ is found to be the most significant measure for this subjective attribute (r = 0.214), followed by RL_{std}. L:D, RL_{avg} and Perimeter. These measures have similar correlation coefficients, indicating that spatial analysis offers a more complete understanding of a visual scene than does merely relying on physical light levels. A further comparison of the objective variables reveals another interesting observation. Despite similar values for $Area_{Light\ patches}$, as in the case of Spot E in Setting I (area = 109120 pixels, mean rating = 4.17) and II (area = 113489 pixels, mean rating = 4.83), there is a discrepancy in the ratings for appropriateness/comfort. An increase in L:D (I = 0.59, II = 0.63) and a decrease in Perimeter (I = 7624.69 pixels, II = 7353.52 pixels) led the participants to prefer Setting II over Setting I.

Combination of the significant measures: Multivariate Regression Analysis

It is worth reminding that the main objectives of this study are to test the analytical framework and the experimental methods, as well as to establish relationships between the subjective attributes and the significant measures ($\rho < .01$ and $\rho < .05$), rather than simply to find best-fit regression lines. To derive a prediction equation — through multivariate regression analysis — for each subjective attribute, we checked for multicollinearity with reference to the tolerance value and variance inflation factor (VIF) of each objective measure. The analysis involved two steps: i) an overall analysis based on all 624 responses; and ii) a group analysis based on the type of occupants. The first analysis shows that there are statistically significant correlations for all the equations, where visual balance (r = 0.21, *Sig.* = .003) and visual clarity (r = 0.57, *Sig.* = .000) are the least and the most correlated with the objective measures, respectively. The second analysis, however, reveals that the objective measures are the least correlated with appropriateness/comfort in the cases involving the conductor (r = 0.44, *Sig.* = .000), but it returns null results for the audience members and the musicians. The weak correlations are in agreement with that obtained from the univariate linear regression analysis.

		r	r^2	*Sig.*	Average VIF
$Brightness_{All}$	$= 1.792 + (0.000480 \times LLM_{std}{:}LRM_{std}) + (0.121 \times RL_{std}) + (1.637 \times L{:}D) + (2.097 \times Spot\ O) + (1.664 \times Spot\ A) + (0.471 \times Spot\ B) + (0.158 \times Spot\ C) + (0.159 \times Spot\ D)$ *where Spot O = 1, Others = 0; Spot A = 1, Others = 0; Spot B = 1, Others = 0; Spot C = 1, Others = 0; Spot D = 1, Others = 0; Spot E = when all dummy variables are set to 0*	0.50	0.25	.000	4.78
$Brightness_{Conductor}$	$= 1.135 + (2.227 \times LLM_{std}{:}LRM_{std}) + (3.969 \times L{:}D)$	0.68	0.46	.000	1.63

Figure 8 Prediction equations for the subjective attribute of brightness [i]

As Figure 8 shows, although the objective measures account for 26% of the variance (r = 0.51) in brightness ($Brightness_{All}$), the percentage becomes almost doubled (r = 0.68) when only the conductor's responses ($Brightness_{Conductor}$) are taken into account. This suggests that different occupants' luminance requirements and judging criteria led to the lower percentage of variance in $Brightness_{All}$. A closer examination of the equation for $Brightness_{Conductor}$ reveals that the subjective judgement of brightness is strongly associated with the relative luminance contrast as seen in the left (LLM_{std}) and right (LRM_{std}) monocular crescents of the visual field.

CONCLUSION

The subjective-objective method, borrowed from acoustic research, is proven to be effective and reliable through an analysis of concert lighting in King's College Chapel. With this method, it is possible to extract hidden information regarding perceptual judgments, alongside factual parameters. Another virtue is that it gives an overview of the effects of light on the occupants' impression, the variances of which could be examined in depth through six subjective aspects: visual clarity, visual balance, visual uniformity, brightness, spatial intimacy, and appropriateness/comfort. This method can also make possible the creation of a positive lighting impression by manipulating the way space, objects, surfaces and people are illuminated. Because this study only tested a limited number of lighting conditions, further research involving a wider range of stimuli and wider range of the objective magnitude of the measures is needed in order to formulate universal relationships between the variables. The significant results obtained from this study demonstrate that the experimental techniques and the analytical framework can be applied successfully to a highly sophisticated context. With easier access to HDR imaging, this method is readily applicable for analysing the quality of light in other complex buildings. Meticulous attention to detail of the luminous environment and its relationship with people is essential. Such an understanding needs to be reflected in the experimental design and setting, for example by reconstructing the visual scene through the use of dummies. Further, it is important to address lighting criteria for different types of occupants when acquiring subjective judgments. This would help us better appreciate the diverse nature not only of the luminous environment, but also of the occupants' perception.

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[i] Acronyms and abbreviations

L_{avg} : Average luminance of the full visual field (cdm^{-2})

L_{std} : Standard deviation of luminance of the full visual field (cdm^{-2})

L_{var} : Variation of luminance of the full visual field (cdm^{-2})

RIM_{whole} : Relative mean of pixel intensity of a full visual image as resolved by the eyes. The pixel intensity value is multiplied by the relative visual acuity as derived from the visual angles subtended at the eye

$RISD_{whole}$: Relative standard deviation of pixel intensity of a full visual image as resolved by the eyes

RL_{avg} : Average of RL value with bright sources isolated from an image, where Relative Luminance (RL) is a ratio of spot luminance to maximum luminance, i.e. RL = ($Luminance_{spot}$ / $Luminance_{max}$) x 100%

RL_{std} : Standard deviation of RL value

RL_{area} : Percentage of area for bright sources as isolated from the calculation of RL_{avg} in relation to the full visual field

Light to Dark ratio (L:D): By converting a coloured image into a two-level greyscale image, the ratio is derived by calculating the total number of white and black pixels.

Total area of light patches ($Area_{Light\ patches}$): Total number of white pixels of a two-level greyscale image

Perimeter: Total length of outer edges around white area of a two-level greyscale image

VA_{Sheets} : Ability to discern fine detail of music sheets or programmes, i.e. $Target_{Luminance}$: $Background_{Luminance}$

Characterization and valorization of shading devices: proposition of a simple and flexible model

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ABSTRACT

This study aims at providing an accurate description of the thermal behaviour of solar shading devices in order to develop a simple modeling which can be integrated in a thermal simulation platform. A 1D model is developed by considering precisely the radiative exchanges in short and long wavelengths, and by integrating ascending laminar flow which takes place between the shading device and the wall (structural skin). The accuracy of this model is confronted with the results of measurements for a textile screen and a simple model based on a parameterization is proposed and discussed.

INTRODUCTION

The increasing development of highly glazed buildings exposed to high solar gain induces a greater use of solar protection solutions such as textile screens or outside climbing plants which allow passive solar gain in winter. However current thermal simulation platforms do not accurately integrate those architectural solutions, especially the induced air flow between the wall and the shading device. This low consideration of those systems implies a weak valorization of their impacts on the building. The study presents a model of heat transfers which are observable at the scale of a wall. Then a simple model based on the use of the total solar energy transmittance of the shading device is proposed and discussed. Such a model allows an easy and quick way to integrate those systems in a thermal study of a building. Furthermore the use of a total solar energy transmittance to characterize those shading devices would help the architect in the design phase, the engineer in order to choose the best solution to fit its criteria and the industries which develop those systems.

EXPERIMENTAL PROTOCOL

In order to quantify the heat flows which take place in the studied configuration, an experimental platform has been built and instrumented (see figure 1) in Bordeaux (Atlantic climate). As represented on figure 2, 5 cm thick glass wool (B) was fixed on an existing wall (A) with two 13 mm thick plaster boards (C); the studied shading device (E) is placed in front of it, delimiting a small ventilated cavity (D). The width of this cavity can be set to 33 mm, 66 mm or 100 mm. The whole system is called ESAW (Exterior – Shading Device – Air gap – Wall).

The instrumentation (figure 3) is made of 18 thermocouples placed at three different heights and at

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different depths, a pyranometer operating on the spectral range 400 to 1100 nm measuring the incident solar flux on the wall, a cup anemometer for the external wind speed and three hot-wire anemometers located in the middle of the air gap at different height. Two shading devices can be monitorized at the same time with an air gap between them that act as a thermal barrier.

Figure 1: Photograph of the instrumented wall for the two wooden claddings

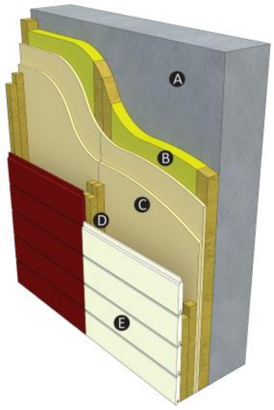

Figure 2: Representation of the layers of materials of the ESAW system

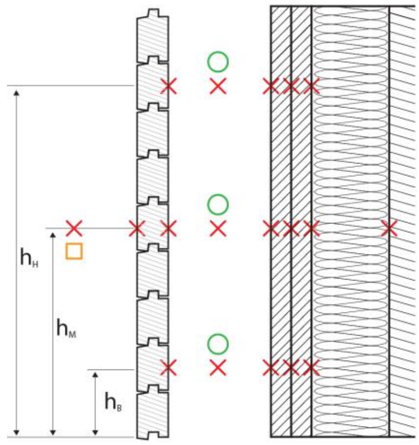

Figure 3: Representation of sensors location. × Thermocouple. ○ Hot wire anemometer. □ Pyranometer and anemometer

Measurements were carried out in June 2012 for two opaque wooden claddings (a light one made of hardwood and a red one made of chipboard), one grey textile screen and one bright expanded metal. A 24 hour span is presented in the figures 4 and 5.

We can notice that maximum air speed in the cavity is 1 m/s and that this velocity is always above 0,1 m/s which traduces the permanent movement in the cavity. Also, the measured velocity at the bottom varies more than the ones measured at medium and high height, this can be explained by turbulences at the bottom of the cavity while the air flow is laminar in the upper part.

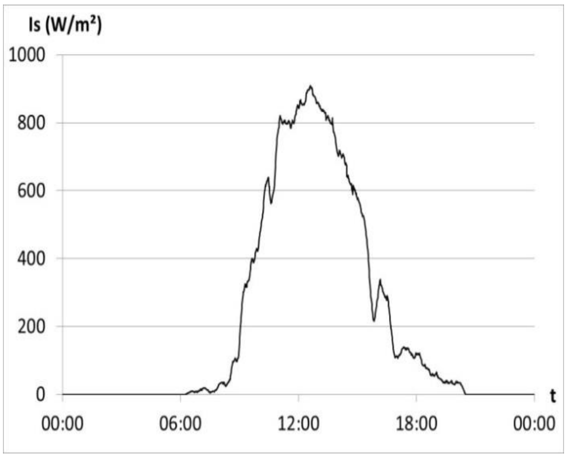

Figure 4: Incident normal radiative flux (W/m²)

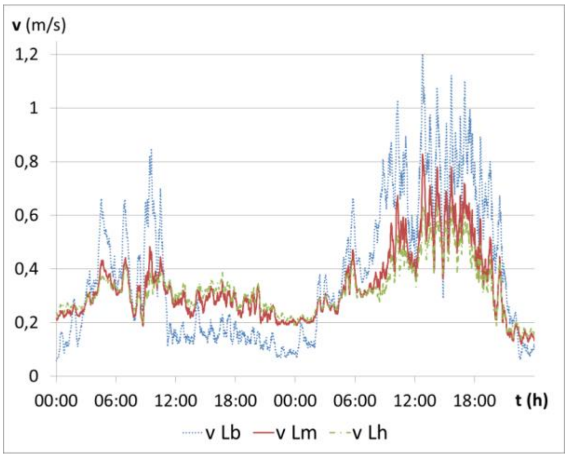

Figure 5: Vertical air velocity inside the cavity in the case of a wooden cladding.

DESCRIPTION OF THE MODEL

The wall is discretized into a set of volumes for which the flux balance is written in a dynamic regime (see figure 6). The temperature in the cavity is considered uniform and corresponds to an average temperature. Modelling is one-dimensional (horizontal direction) and vertical gradients outside the ventilated air gap are neglected. The general model describes radiative, conductive, and convective heat fluxes.

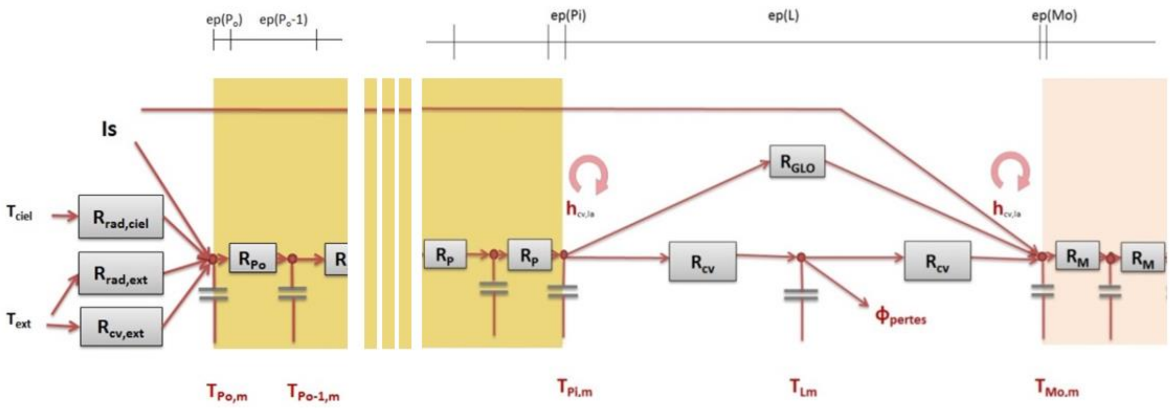

Figure 6: Thermal network for the external part (left) and for the air cavity (right) using the rheoelectrical analogy.

General model

The short and long wave radiative fluxes are differentiated, and we consider the multi-reflexion phenomenon as presented by Rodriguez et al (2007).

For the external convective heat transfer coefficient, we use McAdams (1994) expression:

$$h_{cv,ext} = 5{,}7 + 3{,}8 * v_{ext} \qquad (1)$$

The sky temperature is given by Duffie and Beckman (1974). And the heat loss in the cavity due to the advection can be written such as:

$$\mathrm{Q} = \dot{\mathrm{m}}\mathrm{Cp}\left(\mathrm{T_{ext}\text{-}T_{lame}}\right) \qquad (2)$$

Air flow model, determination of the air velocity and the heat transfer coefficient

Types of models. Different models of natural convection between two plates exist - mostly established for a steady state- which fall into two types. First are numerical approaches that consider the flow (possibly asymmetric) in the walls adjacent to the cavity to establish correlations between Nusselt and Rayleigh numbers. These numerical models were first established experimentally and next using CFD (Aung et al, 1972). In 2011, Gan (2011) sets those correlations more generally for a bigger set of configurations. Although those are limited to situations for which heat fluxes given to the air are between 100 and 1000W/m² and an aspect ratio between 5 and 60. Others approaches are analytical. Considering the chimney effect, the supposed linear pressure profiles outside and inside the cavity can be written and used to determine the air flow. Bansal (1993) and Ong (2003) established such correlations for solar chimneys. The air flow can also be determined by calculating the pressure losses along the channel, especially frictions one. This model by its flexibility and the quality of the predictions it gave, has been selected and will be used in the following.

Determination of the air velocity. In the air cavity in a static regime the driving pressure difference between the air in the cavity and the exterior air balances the resistance to the air flow along the cavity. Considering the air as a perfect gas we can write the driving pressure with air temperatures as made in the norm EN 13363. The resistance to the air pressure is the sum of the pressure losses at the openings (bend and reduction at the bottom and enlargement at the top of the cavity) and along the channel (linear pressure loss by friction), that are here determined using Idel'chik (1994).

Influence of the exterior wind. Measured data shows an influence of the wind velocity on the vertical air speed in the cavity as already showed by Mayer and Künzel (1983). Indeed the wind can affect the air pressure at the outside of the system, and this variation can be taken into account in the model by adding a term in the driving pressure difference as done by Falk (2013). One limit of our study is that the direction of the wind was not measured, so this coefficient is a constant while it should depend on the wind direction.

Convective heat transfer. Once the air flow is calculated, the convective heat transfer coefficient is determined using a correlation between Nusselt and Grashof numbers established for natural convection within the cavity. Here we use Fishenden and Saunders (1950):

$$Nu = 0{,}107Gr^{1/3} \qquad (3)$$

Evacuated heat flux. In order to determine the heat flux evacuated through the air cavity by convection we use an experimental law determined by Hirunlabh (1999) linking the average temperature to the air temperatures at the bottom and at the top of the air cavity.

Resolution

The heat balance on each node gives a linear differential equation (4):

$$\frac{dC_iT_i}{dt} = \sum_j f_jT_j + g(Is, T_{ext}) \qquad (4)$$

Previous set of equations can be written in a matrix form to give equation (5) distinguishing internal and external loads, respectively the matrices F and G, and the vector of temperatures in the wall T and U which corresponds to the incident solar flux and the outside temperature.

$$C\frac{dT}{dt} = FT + GU \qquad (5)$$

The numerical solution of this differential equation is obtained with the implicit Euler method with a time step of 1 minute using Matlab, where matrix F must be recalculated at every step.

VALIDATION OF THE MODEL

In order to validate the proposed modelling we compare the results of the simulation against measurements. Data to be compared are chosen to characterize the behaviour of the system: the heat flow evacuated by convection and the heat flow transmitted through the wall. The first one can be described by the air velocity in the ventilated cavity and the difference of temperature between the top and the bottom of the cavity. The latter by the difference of temperature between the two sides of the second plaster board.

We compare the measured data with results from the model in the case of a textile screen for an air gap width of 100 mm during two sunny days. Air velocity in the air gap is plotted in figure 7, while the gradient of air temperature in the air gap is in figure 8 and the difference of temperature between the two sides of the second plaster board in figure 9.

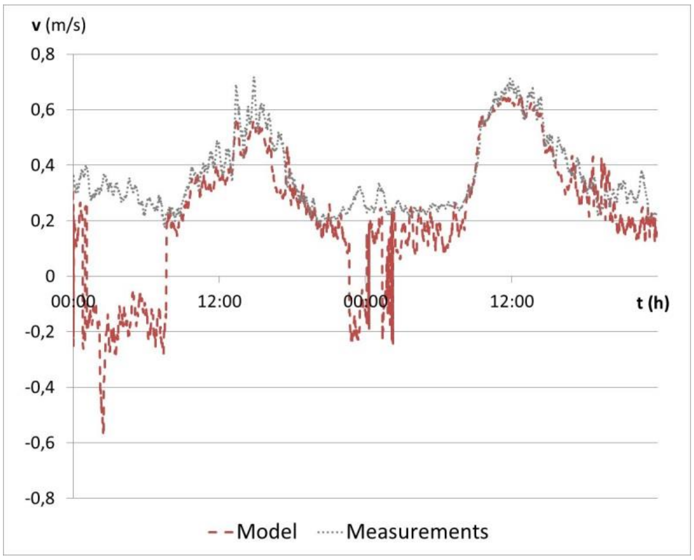

Figure 7: Comparison between estimated and measured air velocity in the cavity

We can see on figure 7 the increase during the daytime of the air velocity inside the air cavity. It is also notable that during the night the calculated air velocity can be negative which means that the sign of the driving pressure can change and would correspond to an air flow from the top to the bottom. But the measurements don't indicate the direction of the air flow, so it could not have been confirmed and it does not have a big impact on the overall behaviour of the system. During daytime the air velocity is quite well estimated by the model.

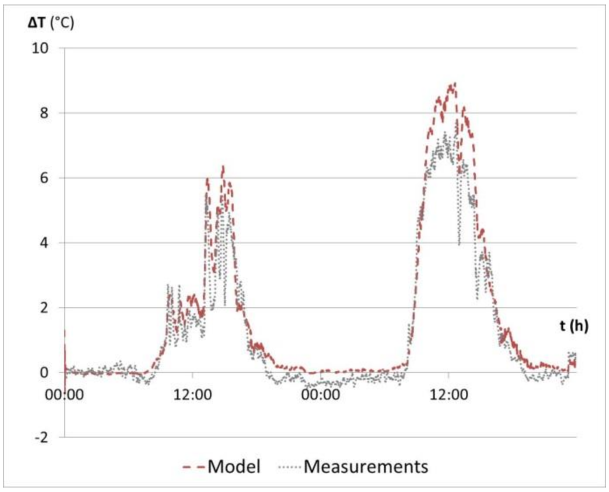

Figure 8: Comparison between estimated and measured gradient of air temperature in the air gap

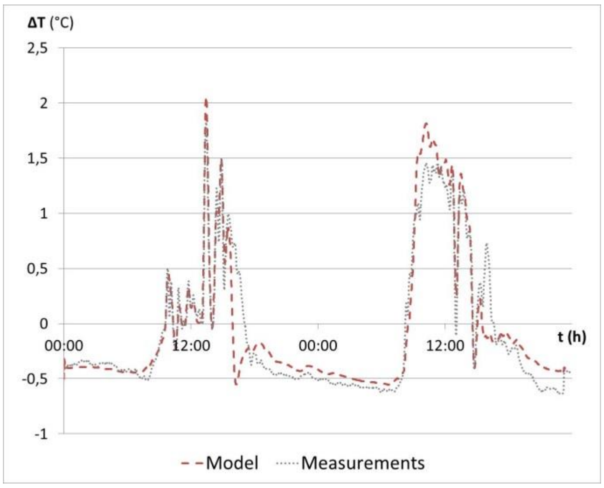

Figure 9: Comparison between estimated and measured difference of temperature between the two sides of the second plaster board.

On figure 8 and 9, we can also see the great variation of temperatures during the daytime due to the solar radiation. The estimations are quite good during the daytime. Still, we can see that the gradient of air temperature is overestimated. It is due to the permeability of the textile screen as there can also be a horizontal air flow that is not taken into account in our model

Results were even better for the two wooden claddings but are quite limited for the expanded metals. The latter has a high reflectivity and a complex 3d shape that are at the limit of the hypothesis of this model. For the three first shading devices both the transmitted heat flux within the wall and the evacuated heat flux by convection are well estimated.

APPLICATION TO A SIMPLE MODEL

Simplified model with the use of the solar transmittance

Definition. The total solar energy transmittance (f_s) of a system is defined as the proportion of incoming solar energy transmitted to the thermal zone behind the system as described in the EN ISO 13363. It depends on the properties of the system but also on the outdoor conditions, indoor conditions, and thermal properties of the elements. The EN ISO 13363 proposes a static calculation which is limited in the case of complex shading devices.

We here consider the characterization proposed by Hellstrom et al (2007). For the total solar transmittance (f_s) of a shading device, the average values are obtained from:

$$f_s = \frac{(Co-He)_1-(Co-He)_0}{S*Is} \qquad (6)$$

where Co and He are the cooling and heating demands for a period of the associated thermal zone maintained at a uniform temperature, indices 1 and 0 indicate with and without solar irradiation and S*Is is the total solar irradiation incident on the shading device during the same period.

In our case the whole system can be decomposed as a shading device with a ventilated air gap and a wall. The total solar energy transmittance of the system can be written as:

$$f_{s_{ESAW}} = f_{s_{SA}} * f_{s_W} \qquad (7)$$

Method of calculation. The method of calculation of the total thermal energy transmittance is as follows. We consider a shading device for a given sunny period, the inside air temperature is fixed at 20°C and we carry four simulations, where heating and cooling loads are recorded:

1. Simulation of the ESAW system taking into account the solar radiation
2. Simulation of ESAW system without taking into account the solar radiation

3. Simulation of the Wall taking into account the solar radiation
4. Simulation of the Wall without taking into account the solar radiation.

The first two simulations are used to calculate the solar factor of the whole ESAW system, and the next two for the solar transmittance of the wall. We then obtain the total solar energy transmittance of the shading device using the equation (7).

Results. Total solar energy transmittance of the 4 considered shading devices that are made of materials with low thermal mass have been calculated using this method for 3 different air cavity widths. Results appear on figure 10. The two wooden claddings differ a lot. It is due to differences in their properties. A lower coefficient of absorption and a lower conductivity for the light hardwood cladding limits the solar transmittance compared to the red dense chipboard. We can also see the influence of the air width. The wider the gap is, the lower the solar energy transmittance is as the heat flux evacuated by convection is greater.

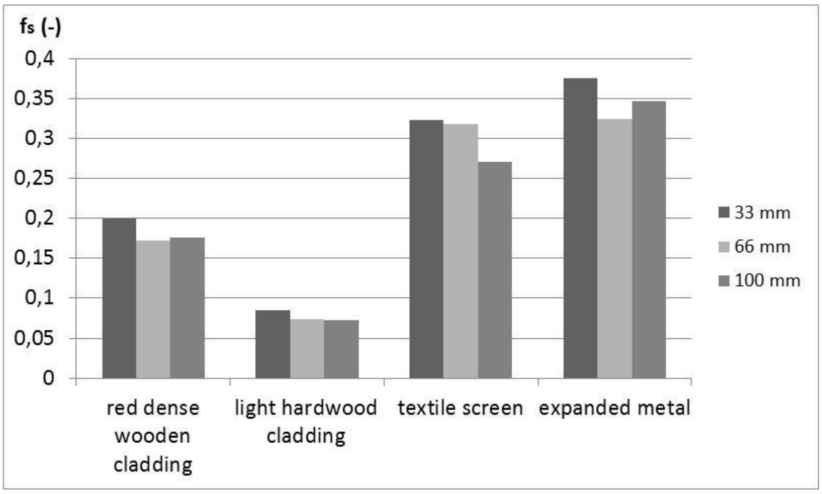

Figure 10: Results of the total solar energy transmittance for the 4 considered shading devices for three different air gap widths.

Discussion. The intrisic nature of this defined total energy transmittance of a shading device has been discussed by analyzing the sensibility of the obtained values to some parameters of the method of calculation such as the insulation width, whether it is placed on the inner part of the concrete or the outer part, the weather file and the fixed temperature of the thermal zone. Results show that the sensitivity is very low. The total solar energy transmittance of a shading device can be useful for the characterization of its impact on the thermal gains of a wall or glazing.

Application to sensibility analysis. In order to evaluate the influence of some design parameters of a shading device on its performance it is possible to analyse the sensibility of the model to those parameters.

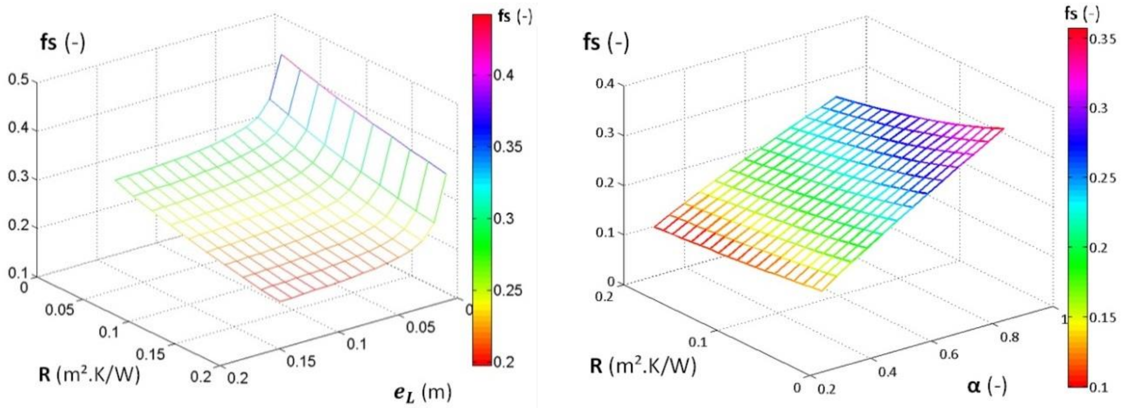

Figure 11: Sensibility analysis of the solar factor of the wooden cladding varying thermal resistance and air gap width (left) and thermal resistance and absorption coefficient (right)

Two examples are shown in figure 11 for a wooden cladding with in the first case the thermal resistance and the cavity width as variables and in the second thermal resistance and air gap width. It is then possible for example to evaluate the way a wooden cladding performance will age with the deterioration of the color.

CONCLUSION

The model presented was aiming at easing the taking into account of a shading device in the modelling of a building. Experiences have been carried out and the set of equations used to determine the velocity in the cavity and the associated convection has been selected among different models. The estimated results from the model are in good agreements with the measurements for the two wooden claddings and the textile screen. But the expanded metal seems to be at the limit of the domain of validity of the model.

Then a simple model based on the use of the total solar energy transmittance has been presented. The shading device can then be replaced by this coefficient in a building simulation platform in order to consider its impact on the building. Furthermore, this total solar energy transmittance allows the characterisation of its impact and as so help architects and engineers in quickly assessing its impact without using complicated models which can’t be used at the early phase of a the design of a building. Finally the complete model can be used to make some optimization in order to produce a shading device that will correspond to a set problem.

NOMENCLATURE

α = absoption coefficient (-)
e = width cavity (m)
f_s = Total solar energy transmittance (-)
I_s = Total solar incident radiation (W/m²)
Gr = Grashof number (-)
Nu = Nusselt number (-)
R = *Thermal resistance (m².K/W)*
T = Temperature (K)
v = Air velocity (m/s)

Subscripts

b = bottom
m = medium
h = top
ext = exterior
cv = associated to convection
rad = associated to radiation
lame, L = air gap

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Testing a Method to Assess the Thermal Sensation and Preference of Children in Kindergartens

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ABSTRACT HEADING

This paper presents the results of a method to obtain the subjective response of children regarding their thermal environment in naturally ventilated kindergarten classrooms. The study was conducted in two kindergartens located in the city of Medellín, Colombia (latitude 6.25°N, longitude 75.5°W and altitudes of 1610m and 1715m above sea level). The research involved the application of thermal comfort questionnaires in children aged between 4 and 5 years old through a tool called "Lottery" and simultaneous measurement of the indoor thermal environment (air temperature, globe temperature, relative humidity and air velocity). Outdoor climate was also measured for at least 7 days before the application of the questionnaires. The questionnaire was developed together with a cognitive psychologist and the school teachers and was previously tested in a third school. The tool used (lottery) was designed based on scales to assess the thermal sensation and preference: ASHRAE 55 and McIntyre, respectively. Each child was individually assessed within the classroom during October/November 2013. Cognitive development evaluations and psycho-emotional surveys were also performed to obtain the intellectual coefficient of each child. Most of children seemed to understand the questions. Through this study it was possible a better understanding of children's thermal sensation and preference in the tropical climate.

INTRODUCTION

In Medellín city, recent government politics have encouraged the development of public education policies and physical infrastructures. The "Buen Comienzo" program of the Municipality of Medellín seeks to improve the care of children in early childhood (0 to 5 years old). One of the criteria from this program refers to the quality of the spaces and based on such criteria, several infrastructures have been designed and constructed in different parts of the city. The role of architects was center on the design of physical spaces that enable the development of various educational activities, considering the characteristics of the thermal, lighting and acoustic environment due to the influence on cognitive development and behavior of the occupants.

In thermal comfort area the existing researches and international standards to assess indoor environments only consider adults and healthy people. In the case of children, the differences in their metabolism, body surface area, type of clothing and preferences should be considered when assessing perception and acceptability of the thermal environment (Parsons, 2003; Mishra & Ramgopal, 2013). The international standards ISO 9920 (2007) and ASHRAE 55 (2013) provide data for adult clothing. Al-Rashidi et al. (2012) studied three methods to calculate the clothing insulation and body surface area of children between 6 and 17 years old. Due to the fact that the study was conducted in Kuwait, cultural aspects were determinant in the definition of the type of clothing, especially to girls.

In the last decades, several studies in which the target populations were students have been performed (Kwok, 1998; Kwok & Chun, 2003; Wong & Khoo, 2003; Hwang et al., 2006; Al-Rashidi et al., 2009). In other studies, thermal sensation and preference were assessed in schools, adjusting the ASHRAE 55 (Liaison et al., 2010) and McIntyre scales (Haddad et al., 2012; De Giuli, Da Pos, & De Carli, 2012; d'Ambrosio Alfano, Ianniello, & Palella, 2013; Corgnati, Ansaldi, & Filippi, 2009), respectively.

Haddad et al. (2012) tested three techniques to get the thermal preference and acceptability of children between 11 and 12 years old. The authors submitted their questionnaire model to a previous review, conducted by psychologists, whom examined the simplicity and structure of the questionnaire. As this research was conducted with children with reading and writing skills developed, the researchers were also able to test the three different scales of response assessed by Laerhoven et al. (2004): Likert, Visual Analogue Scale and Numerical and Visual Analogue Scale - the three scales were based on the 7-point scale of ASHRAE 55 (2013).

Conceição et al. (2012) presented the application of a model of adaptive comfort in naturally ventilated preschool classrooms. Even though the authors mention the application of thermal comfort questionnaire (based on ASHRAE 55), they do not make any considerations on the method used for interviewing children between 3 and 5 years old or if children have the ability to decide when to open or close a window, for example.

The research conducted by Fabbri (2013) with children in preschool age deals with a method to assess the subjective preference and acceptability of the thermal environment, and compares these results with the calculated PMV and PPD. Results indicated, according to the author, the understanding of the tool and the questions by children. Furthermore, the author suggested paying more attention to the psychological component.

OBJECTIVE

The aim of this study was to test a method to obtain the evaluation of thermal environment of children, between 4 and 5 years old.

METHOD

This study assessed the thermal sensation and preference of children between 4 and 5 years old in their classrooms. Environmental data were obtained by measurements of air temperature, globe temperature, relative humidity and air velocity. Thermal evaluations were obtained through the application of a questionnaire adapted to the characteristics of the target population and the climate of the city.

Place of study

Medellín city is located in the tropical zone (latitude 6.25°N, longitude 75.5°W) of the Andes Mountains, with altitudes between 1550m and 2000m above sea level. According to Köppen-Geiger climate classification the city has an Equatorial Climate (Kottek et al., 2006).

Figure 1 shows the mean monthly outdoor air temperature, relative humidity and rainfall for Medellín (IDEAM, 2014). Temperature conditions are stable throughout the year while the relative humidity varies according to rainfall. This climatic feature influenced the design of the questionnaire.

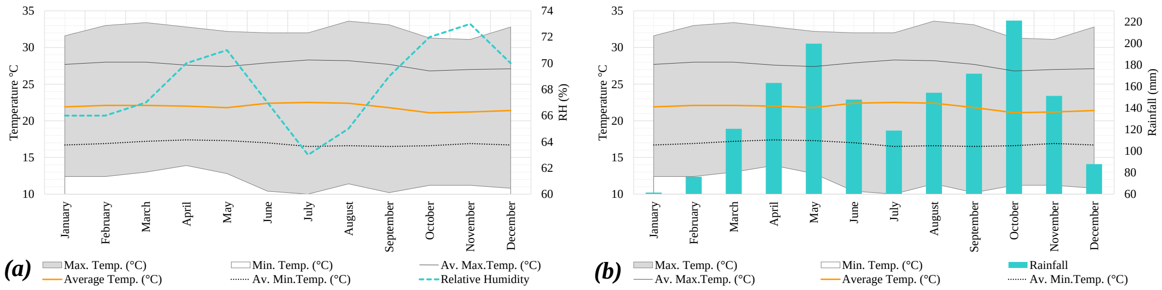

Figure 1: ***(a)*** *Averages of temperature vs. Relative humidity. Medellíın City.*
(b) *Averages of temperature vs. Rainfall. Medellín City*

According to García (2011) until the year 2011, from the 184 kindergartens existing in the city, 60 were built following the considerations of the Colombian Technical Standard 4595 for Educational Institutions (NTC 4595, 1999). For this study there were selected two classrooms from two kindergartens that attend NTC 4595: *"Brisas de Robledo"* (1715m above sea level) built before the standard reviewed in 1999 and *"12 de Octubre"* (1610m above sea level) built in 2010. Figure shows the general characteristics of the evaluated classrooms. *"Brisas de Robledo"* classroom has a square floor plan, uniform ceiling and brick walls. *"12 de Octubre"* classroom has an irregular plan, variations in ceiling heights and walls with foil insulation.

Figure 2: *Classrooms where children were assessed and location of sensors.*

Psychological assessment of children

In order to apply the test in children with appropriate cognitive and emotional level, it was conducted a previously interview with the teachers of each classroom. The interview allowed identifying the children between 4 and 5 years old who could participate actively in the research (playing the lottery).

The Weschler Intelligence WIPPSI III for preschoolers was applied in all children of the two classes allowing to determine their intellectual capacity and to verify that the pre-selected children did not have any kind of cognitive dysfunction. The results of this test indicated that, although some children have lower intellectual coefficient than others, they all were within the normal range for the age (IQ between 85 -115).

Afterwards it was constructed a scale of observation of the behavior to appraise children participating in the test. BASC-2 (Behavior Assessment System for Children) test was applied to the parents and teachers to compare the observation of behavior –from each child- in different environments in order to validate the data obtained from observation. BASC-2 system enables assessment from three points -self, teacher, and parent- to help ensure a balanced evaluation (Reynolds, Cecil and Kamphaus, 2014). The standardization of this instrument was carried out in Medellín by the Group of Neuropsychology and Conduct and Neuroscience Group of University of San Buenaventura, Neurological Institute of Antioquia and University of Georgia. The methodology and results of the psychological and cognitive assessment will be the aim of another paper.

Designing and application of tests

According to Borgers and de Leeuw (2000) and Borgers, Hox, & Sikkel (2003) it is possible to apply questionnaires in 4 years old children, although it is not an easy task. The development of the questionnaire should help on the first two parts of the formulation of a question: the understanding of it and the recovery of the relevant information. These can be achieved by using words of children's language and game activities. According to that, the design of the instrument included two important issues: the methodology needed to address questions to the children and the characteristics of the local climate. The survey questions were formulated based on ASHRAE 55 and 3 points McIntyre scales. For the climatic conditions of Medellín, the ASHRAE 7-point scale was reduced to 3 points in order to facilitate understanding by children. Table 1 shows the questions and the alternatives of answers.

The first question (Q1) allowed us to verify whether children understood the images and their symbolic content, concerning the conditions of the day. The second question (Q2) asked children about their feeling with the thermal conditions at the moment in the classroom –thermal sensation-. The questions three (Q3) and four (Q4) were used to obtain the thermal evaluation. Question 3 (Q3) asked children about their feeling with the thermal conditions answered in Q2 and Q4 was used as control to Q2 (if the child answers the room was hot then he/she should answer to wear fewer clothes). The fifth question (Q5) helped to identify the thermal preference.

The use of a lottery as a tool to apply the questionnaire was defined with the assistance of psychologists. This game allowed children to interact with the instrument and allowed us to vary how to play (in this case, children would cover only the image corresponding to the chosen answer for each question). The images used in the lottery should be clear, known by children and easy to associate with the answers. Furthermore, it was avoided to use colors related to the sex of children, for example. The use of male and female icons on issues relating to the evaluation and thermal preference was recommended. It was created one lottery for girls and another one for boys. Figure 3 shows the graphical features of the game. The selected children played the lottery individually inside the classroom with the help of a researcher of the team. Before starting, the researcher presented for each child the rules of the game.

The response images to each question were arranged in columns. When the game-questionnaire started the lottery was completely covered and only when a question was made the pictures of response were uncovered. Each child should find the twin image (representing the choice) and cover it on the board. The pictures were arranged randomly in each column of the board to avoid children related pictures on the previous issue with the images of the following question. Each child took approximately 5 minutes to complete the game.

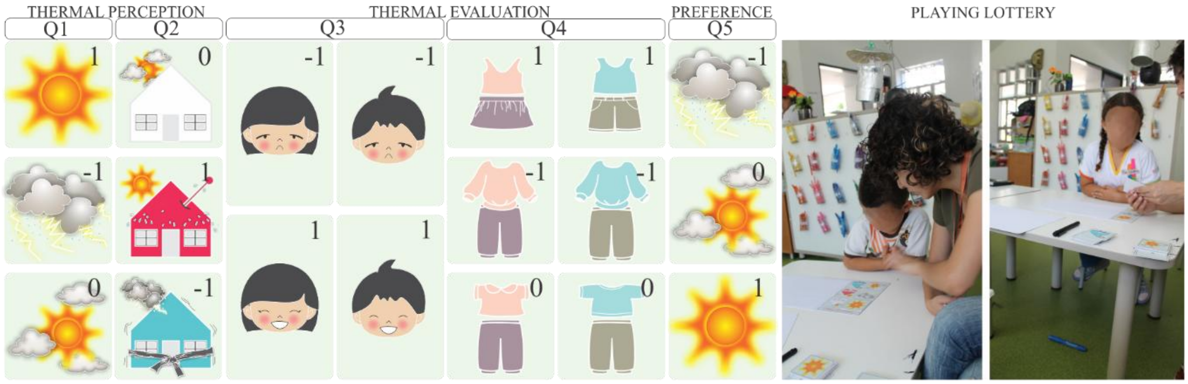

Figure 3: *Lottery*

In order to verify if children will understand the questions, the images and how to play the lottery, a pre-test was performed in a third space. Adjustments in the form of the images and how to ask the questions were realized accordingly.

Experimental protocol

Indoor measurements of the four main environmental variables (air temperature, globe temperature, air velocity, relative humidity) were performed in the mornings on days October 30, 2013 in Brisas de Robledo kindergarten and November 06, 2013 in 12 de Octubre kindergarten. Figure 2 shows the location of the sensors in classrooms. Outdoor climate (air temperature and relative humidity) was also measured for at least 7 days before the application of the questionnaires.

Simultaneously with the measurements, the thermal comfort questionnaires (lottery) were applied. The clothing insulation (clo) was obtained through ASHRAE 55 (2013) tables and considered the children's clothing during the lottery. Children were performing reading/drawing activities, before and after the lottery.

RESULTS

Table shows the responses obtained through the lottery applied in children in each classroom, in percentage. Table summarizes the general characteristics of the sample and the climate during the period of fieldwork.

Regarding the thermal perception in the morning (Q1), 80% of children perceived a "sunny morning" and only 20% a "cloudy with sun" morning. The thermal perception of the classrooms (Q2) was perceived by 45% of children as "hot", by 30% as "not hot neither cold" and by 25% as "cold".

Considering all children (Q3), when the classroom was "cold", 10% of the kids were "sad" with this condition and 15% were "happy". 20% of children were "sad" and 10% were "happy", when the classroom was perceived "not hot neither cold". Children who perceive the classroom "hot" said that they felt "sad" (15%) and "happy" (30%).

15% of all children would wear "jersey and pants" when the classroom was "cold", 5% would wear "T-shirt and pants" and just 5% would wear "sleeveless shirt and skirt/shorts". When the classrooms were perceived "not hot neither cold" 25% of children would wear "jersey and pants", 10% would use "T-shirt and pants" and 10% would wear "sleeveless shirt and skirt /shorts". When the classrooms were perceived "hot" by children, 10% of them would wear "jersey and pants", 10% would wear "T-shirt and pants" and 25% would wear "sleeveless shirt and skirt/shorts".

Table 1: Children's answer to each question of the lottery.

		Kindergarten classroom					
1. THERMAL PERCEPTION		***12 de Octubre***			***Brisas de Robledo***		
Q1: How do you think is the morning today?							
a. The day is cloudy	**-1**	0%			0%		
b. The day is cloudy with sun	**0**	0%			**40%**		
c. The day is sunny	**1**	**100%**			**60%**		
Q2: How do you think is the classroom in this morning?							
a. The classroom is cold	**-1**	**20%**			**30%**		
b. The classroom is not hot neither cold	**0**	**30%**			**30%**		
c. The classroom is hot	**1**	**50%**			**40%**		
2. THERMAL EVALUATION		***12 de Octubre***			***Brisas de Robledo***		
Q3: When the classroom is ______, How do you feel?		Q2 (-1)	Q2 (0)	Q2 (1)	Q2 (-1)	Q2 (0)	Q2 (1)
a. Sad, gloomy	**-1**	**10%**	**10%**	**20%**	**10%**	**30%**	**10%**
b. Joyful, happy	**1**	**10%**	**20%**	**30%**	**20%**	**0%**	**30%**
Q4: When the classroom is ____, What clothes would you wear?		Q2 (-1)	Q2 (0)	Q2 (1)	Q2 (-1)	Q2 (0)	Q2 (1)
a. Jersey and pants	**-1**	**10%**	**10%**	0%	**20%**	**10%**	**20%**
b. T-shirt and pants	**0**	0%	**10%**	**20%**	**10%**	**10%**	0%
c. Sleeveless shirt and skirt/ shorts	**1**	**10%**	**10%**	**30%**	0%	**10%**	**20%**
3. THERMAL PREFERENCE		***12 de Octubre***			***Brisas de Robledo***		
Q5: At this moment,would you like to feel ____?							
a. Cooler	**-1**	0%			**10%**		
b. No change	**0**	**60%**			**30%**		
c. Warmer	**1**	**40%**			**60%**		

Table 2: Characteristics of the sample and the climate during the period of fieldwork.

Kindergarten classroom	***12 de Octubre***	***Brisas de Robledo***
Gender		
Boys	40%	40%
Girls	60%	60%
Age		
4 years	20%	40%
5 years	80%	60%
Mean Clo	*0.50*	*0.56*
Mean Met	*1.0*	*1.0*
Monthly mean outdoor air temperature (ºC)	*21.2*	*21.1*
Mean daily outdoor air temperature - 7 days ago (ºC)	20.2	*21.4*
Mean indoor operative temperature (ºC)	24.8	24.6
Mean indoor relative humidity (%)	56.2	59.9
Mean indoor air velocity (m/s)	0.28	0.19

In the evaluation of the thermal preference (Q5) of the total number of children assessed, 5% said they would like to feel cooler at that time, 45% said they were satisfied (no change) with the current conditions and 50% would like to be warmer.

The mean votes of thermal sensation (Q2) and the mean votes of preference (Q5) was (a) 0.1 and 0.5 for Brisas de Robledo and (b) 0.3 and 0.4 for 12 de Octubre, respectively. These results suggested that children, at the moment of the application of the lottery, feels slightly warm environment but prefer to feel that way or warmer.

Comparing the actual mean votes with PMV/PPD and adaptive model of thermal comfort

The PMVc (calculated Predicted Mean Vote) (ISO 7730, 2005) for Brisas de Robledo was -0.61 with a PPD (Predicted Percentage of Dissatisfied) of 18.27%. For 12 de Octubre the PMVc was -0.87 and the PPD was 22.01%. In both classrooms the PMVc resulted in a slightly cooler environment whereas the actual sensation presented a neutral/slightly warm one. Maybe such difference could be caused by the adoption of adult's metabolism. If we consider that 1.0 met for adults is equal to 1.2 met for children (Fabbri, 2013) the new calculated PMV are -0.08 for Brisas de Robledo and -0.28 for 12 de Octubre, more closer to the actual values and indicating thermal comfort if we considered a range of PMV from -0.5 to 0.5.

Applying the data into the adaptive model of thermal comfort (ASHRAE 55, 2013) we obtained 90% acceptability ranges of 21.8 to 26.8ºC for Brisas de Robledo and 21.9 to 26.9ºC for 12 de Octubre when using the mean monthly outdoor air temperature; the ranges varied very little when the running mean temperature (7 days ago with α=0.9 – ASHRAE 55, 2013) was used instead the mean monthly temperature. This way, the measured data (mean indoor operative temperature of 24.6ºC for Brisas de Robledo and 24.8ºC for 12 de Octubre) was within the ranges for thermal comfort in both kindergartens.

CONCLUSIONS

This study allowed us to test a method for evaluating the thermal sensation and preference of children of pre-school age in the city of Medellín, Colombia. Due to the age and development process of children, psychologists and pedagogues were essential in formulating questions, defining the questionnaire methodology (lottery) and selecting images to be used. However, the fact that the lottery was conducted by a stranger person to children and untrained in pedagogy for preschool may have generated some sort of impact on the formulation of the questions and therefore the answers. In a future study, the lottery could be applied by children’s teacher, minimizing the errors generated by this situation. It was also confirmed the importance of making a brief introduction to try to understand how children perceive the concept of temperature and climate.

The results obtained using the lottery were considered positive from the methodological point of view since the children were familiar with this type of game and understand how it should be played. The purpose of Q1 was to identify whether children related the hot with sun and cold with rain/clouds, for example. This association was confirmed in the answers and it is a typical characteristic of the climate of Medellín. Questions 2 and 5 seemed to be understood by children. Analyzing Q3, it seems that the question was not formulated properly or it was not clear to the children, because, they said they always want to be happy. The selection of clothes (Q4) is a topic that children associate more with the weather. However, it was not clear whether the children actually selected the type of clothes they would like to use or simply selected the type of clothing they prefer (some children choose to wear more clothes even feeling hot, as others selected to wear less clothes even feeling cold).

The results presented herein suggested that children feels slightly warm environment and prefer to feel that way or warmer.

The method should be adjusted regarding the factors that led to some kind of influence on the answers or that did not generate the expected/desired response. Finally, it is important to consider in the design of tools and questionnaires the characteristics of the local climate, as well as cultural factors. These factors influence the construction of knowledge and understanding of the environment, especially in the first years of life.

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Analysis of the Contribution of the Building Elements for Improving the Airtightness in Residential Buildings

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ABSTRACT

The purpose of this study is to investigate the air leakage parts and analyze the airtightness in newly constructed apartments. For the study, the blower door and tracer gas tests were used to measure air leakage rate. Four parts in the building were applied and the measurements were conducted to obtain the air leakage rate of those parts. As a result, the air leakage rate was 0.7~1.0(ACH50) when all parts were sealed. On the other hand, the value was 1.6~2.7(ACH50) under unsealed condition. Considering these reults, it can be assumed that the airtightness of newly constructed apartments was quite tight. In addition, the results showed that the parts of the air leakage were mainly affected in order by, the entrance door, windows, mechanic 2 (air system), mechanic 1 (water system), and electric. By improving these parts, it will be expected to improve the airtighteness for residential buildings. Furthermore, building energy can be saved and provide more comfortable environments.

INTRODUCTION

In most residential buildings, indoor-outdoor air exchange is primarily attributable to air leakage through cracks and construction joints and can be induced by pressure differences due to temperature differences, wind, operation of auxiliary fans, for example, kitchen and bathroom exhausts, and the operation of combustion equipment in the building. Air leakage of buildings can cause many problems, including reduced thermal comfort, degraded indoor air quality, moisture damage of building envelope components, and increased energy consumption. For example, air leakage have caused an increased of energy costs of up to 30~40% during heating period and 10~15% for cooling. In addition, air leakage can have detrimental effects on how a building functions and reduces the life span of a building. The objective of this study is to investigate the air leakage parts and analyze the airtightness in newly constructd apartments. The blower door and tracer gas tests were used to measure air leakage rate. Four parts : electrical parts, mechanical parts-1(the water system), mechanical parts-2(the air system), and architectural parts (window systems) in the building were applied to predict the air leakage area. These elements were sealed to measure the air leakage rate and it was analyzed the airtightness by unsealing each part.

2. BUILDING ENVELOPE AIR LEAKAGE MEASUREMENT

Building envelope air leakage can be measured with pressurization testing, commonly called the blower-door test and tracer gas method. For this research, a blower door test was conducted and the results were compared with the tracer gas decay method.

2.1 Blower Door Test

A fan pressurization airtightness test is relatively quick and inexpensive, and it characterizes building envelope airtightness independent of weather conditions. For this test, a large fan or blower is mounted in a door or window and induces a large and roughly uniform pressure difference across the building shell [ASTM Standards E779 and E1827, Canadian general Standards Board(CGSB) Standard 149.10, ISO Standard 9972]. The airflow required to maintain this pressure difference is then measured. The building that has higher leakage, the airflow necessary to induce specific indoor/outdoor pressure difference is higher. The airflow rate is generally measured at a series of pressure differences ranging from about 10 to 75 Pa.

The pressure difference and flow data are generally fit to a curve using the power law equation. Once the values of *C* and *n* are obtained from the test data, the Equation(1) could be used to predict the airflow rate though the building envelope at any given pressure difference.

$$Q = c(\Delta P)^n \qquad (1)$$

Where,

Q = airflow through openings [m^3/s], **c** = flow coefficient [$m^3/s.Pa^n$],

n = pressure exponent [dimensionless]

2.2 Tracer Gas Measurements

The tracer gas is released into the building in a specified manner. The concentration of the gas in the building is monitored related to the building air exchange rate. Various tracer gases and associated concentration detection devices can be used. All tracer gas measurement techniques are based on a mass balance of the tracer gas in the building.

Three different tracer gas procedures are generally used to measure air exchange rate,

1. Decay or Growth
2. Constant Concentration
3. Constant Injection

Table 1. Measurements of airtightness and Features

Measurements		Contents / Features
Blower Door Test	Pressurization Depressurization	- This is used to measure the airtightness level of building envelopes, and to diagnose and demonstrate air leakage problems.
Tracer Gas Method	Decay or Growth	- The simplest tracer gas measurement. (also known as step-down or step-up method) - It is necessary to mix tracer gas well.
	Constant Concentration	- The tracer gas injection rate is adjusted to maintain a constant concentration within the building. - The best suited for longer-term continuous monitoring of fluctuating infiltration rates.
	Constant Injection	- The tracer is injected at a constant rate. - It is particularly useful in spaces with mechanical ventilation or with high air exchange rates.

For the present study, the decay method was used to measure the tracer gas. A small amount of a tracer gas was injected into the space and was allowed to mix with the interior air. To mix tracer gas well, a fan in each room was installed.

Assuming that the outdoor concentraition was zero and the indoor air was well mixed with the tracer gas, the total balance form was used for Equation(2). After the injection, F=0 and the solution Equation(2) became Equation(3). It is generally used to solve for *I* (air exchange rate) by measuring the tracer gas concentrarion periodically during the decay.

$$V\left(\frac{dC}{d\theta}\right) = \mathrm{F}(\theta) - Q(\theta)C(\theta) \qquad (2)$$

$$I = \frac{\ln C\,(\theta) - \ln C_0}{\theta} \qquad (3)$$

Where,

V = volume of space being tested[㎥], ***dC/d θ*** = time rate of change of concentration[s^{-1}],

F(θ) = tracer gas injection rate at time[㎥/s], ***Q(θ)*** = airflow rate at time[㎥/s]

I = air exchange rate[s^{-1}], ***C(θ)*** = tracer gas concentration at time θ, ***θ*** = time [s]

3. MEASUREMENT

Descriptions of the test units. To measure the airtightness of the building envelope, three different types of apartments at three places in South Korea were chosen (Table 2). The selected units of apartments were popular residential buildings and they were newly constructed in 2012 and 2013. The airtightness test of the buildings was conducted in July through October of 2013.

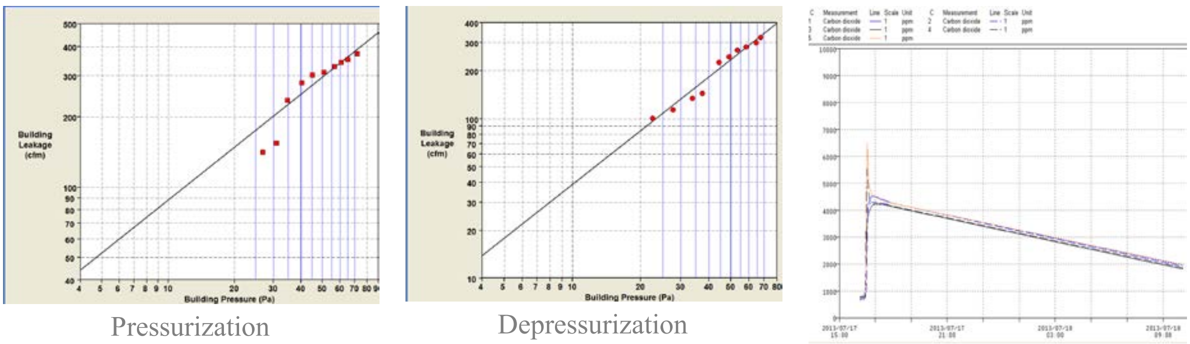
Table 2. Descriptions of the test unit

Measurement Unit	**A**	**B**	**C**
Location	Incheon	Gyeonggi-Do	Daegu
Unit Size	101 ㎡	116 ㎡	84 ㎡
Completion date	September, 2012	June, 2012	September, 2013
Measurement date	July, 2013	September, 2013	October, 2013
Plan			

Method. The airtightness of building envelopes was measured using the fan pressurization test in which a fan was used to create a series of pressure differences between the building interior and the outdoor. A blower door was installed at the entrance door (Fig.1). All the interior doors were opened to equalize the indoor air pressures in the unit. The airflow rates through the fan were also measured. Elevated pressure differences of up to 75 Pa were used to override weather conditions and provide measurements of the physical airtightness of the exterior envelope of the building.

A data logger with pressure difference sensors was employed to continuously collect and display the pressure differences. The pressure sensors were attached to the blower door flow nozzles to allow for the calculation of airflow through the fan.

(a) Fan Pressurization Equipment *(b) Blower Door - Fan* *(c) Tracer Gas Equipment*



(d) Results on display using blower door *(e) Result using Tracer Gas*

Figure 1 Measurement equipment and the results on monitor

Four leakage parts were divided to predict the contribution of the airtightness.

① Electrical parts in the unit – speakers, monitors of meter, sensors for fire, distribution panelboards and communications connectors

② Mechanical parts 1(realted to the water system) in the unit – water supply and drainage line for the kitchen, bathroom, and laundry room

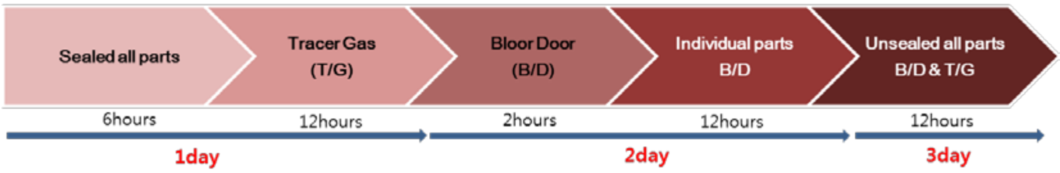
③ Mechanical parts 2(realated to the air system) in the unit – ventilation system, exhaust duct line for the restroom, and the kitchen hood

④ Architectural part in the unit – window system

Platstic films and duct tapes were used to seal each part. After sealing all parts, the airtightness was measured using the tracer gas and the blower door. In addition, the airtightness measurements with unsealed electrical parts were performed using the blower door. Other airtightness measurements were conducted as shown in Table 3.

Table 3. Measurements

Method	Measurement
Blower Door	❶ all parts were sealed ❷ only electrical parts were unsealed & others were sealed ❸ electrical and mechanical-1 parts were unsealed & others were sealed ❹ electrical, mechanical-1, and mechanical-2 parts were unsealed & windows were sealed ❺ all parts were unsealed
Tracer Gas	❶ all parts were sealed ❷ all parts werd unsealed




(a) eletrical parts were sealed


(b) mechanical parts 1(water system) were sealed


(c) mechanical parts 2(air system) were sealed


(d) architectural parts(window system) were sealed

Figure 2 The pictures of each sealed part

4. RESULT

4.1 Air leakage rate

ACH(Air Change per Hour)50 is defined as airflow rate by the gross internal volume of the unit when a 50 Pa pressure difference is applied between indoor and outdoor environments. Fig.3 shows the value by using the blower door. When all parts in the units were sealed, the ACH50 value for units A, B, and C were 0.69, 0.69, and 1.0 respectively. When all parts were unsealed, the results of the ACH50 were 1.63, 2.28, and 2.73. The difference of the ACH50 in each unit between sealed and unsealed was about 1.0 ~ 1.7. When A and B units were sealed, the values were the same. However, the result was different when they were unsealed.

The tracer gas method (Decay) to unit A and B were also conducted. It measured natural conditions such as infiltration without artificial pressure differnences. As shown in Fig.4, the ACH values were very small and the units were very tight because of two reasons. One is that newly constructed apartments were made tighter and the other is that the temperature difference between interior and exterior was small about 2~5℃. It is necessary to study the effect of climatic conditions on these infiltration measurements.

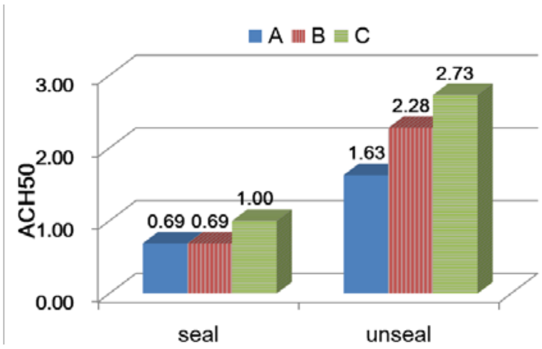


Figure 3 ACH50 using Blower Door

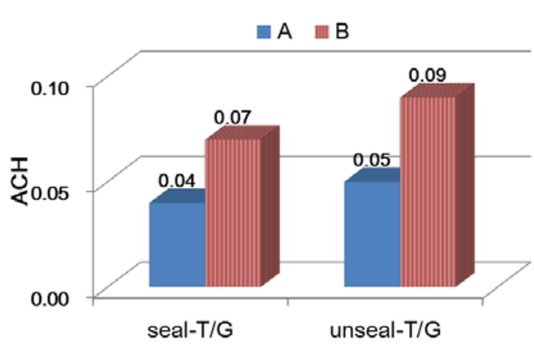


Figure 4 Airflow rate using Tracer Gas

4.2 Airtightness according to each part

Fig.5 shows the results of the tests in Table 3. In unit A, there were little different ACH50 values(0.69, 0.71, 0.71, and 0.78) before unsealing the architectural parts. However, ACH50 increased by 1.63 after unsealing the windows in unit A. The airtightness was influenced largely by the gap between window frames and a difference of construction for the installation of the windows in the walls. In unit B, the ACH50 increased by 1.82 after unsealing mechanical parts-2. In the case of unit B, the mechanical parts-2 caused the largest difference in airtightness. In unit C, the ACH50 value was largely influenced by the mechanical parts-2 and windows.

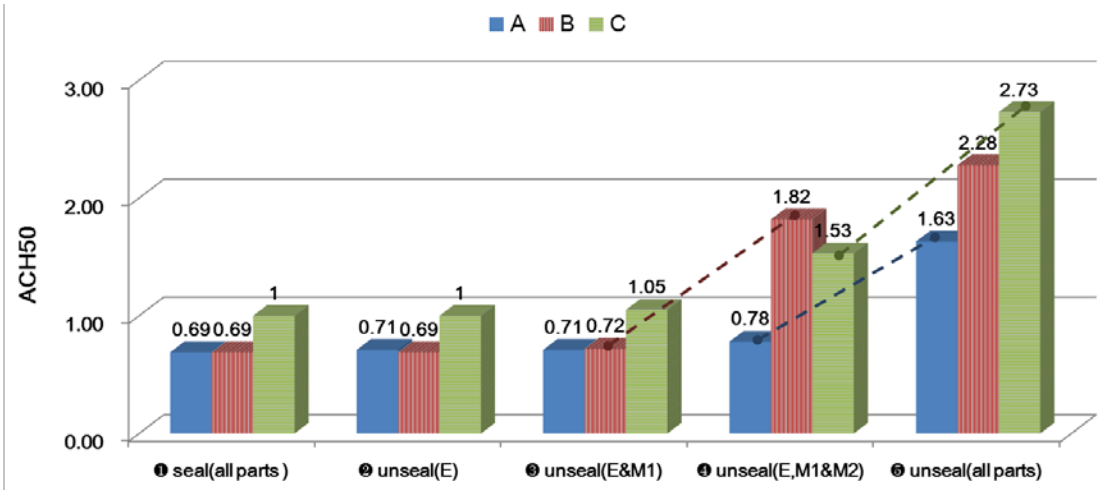


Figure 5 ACH50 using Blower Door

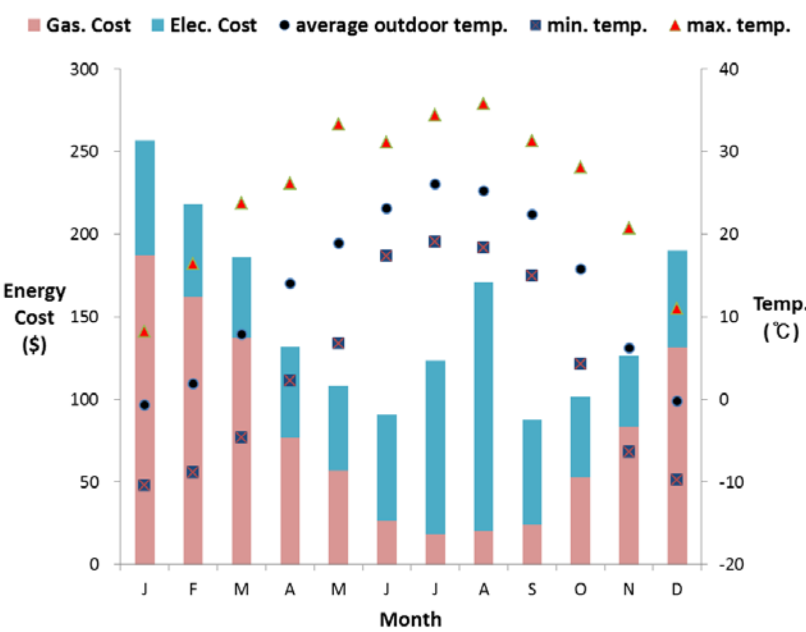
Therefore, the air leakage area was influenced by the mechanincal-2 parts and the window parts. If thechnology to improve the airtightness of these parts is developed, the air leakage rate will be decreased.

4.3 The airtightness of the door

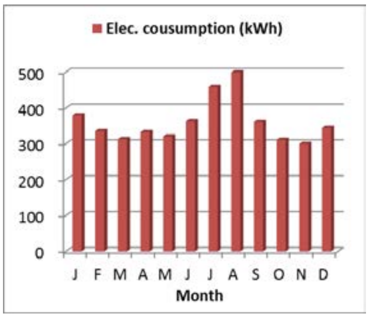
To confirm the entrance door's airtightness, a fan was installed on the other door under the same conditions. The ACH50 was 4.56 and incresed about 1.8(ACH50) higher than the fan mounted on the main door when all parts were usealed. Under sealed condition, the original value of ACH50 was 0.69. After changing the fan's location, the ACH50 was 1.28. The air leakage rate of the main door was much higher than that of other parts.

4.4 Cost savings by reducing air leakage

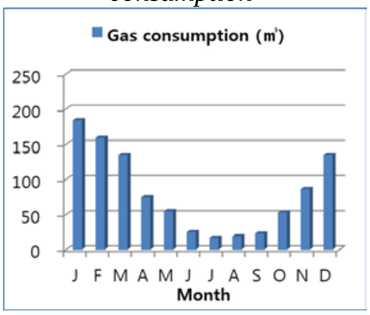
Fig.6 (a) shows monthly energy costs for a typical residential house in Korea. And it is also shown high, average, and low monthly temperatures. In winter, heating cost using a boiler is 130~200$/month. In summer, cooling cost using an electric air conditioner is 60~80$/month. By reducing air leakage, energy cost would be saved, especially heating cost. We don't know the saving cost through this study, but it could save 30~40% cost during heating period and 10~15% cost for cooling by referencing other study. Future studies will be required the quantitive data between energy consumption and air leakage from newly constructed residential buildings.



(a) Monthly electric and gas costs & high, average, and low Temperature



(b) Monthly electric consumption



(c) Monthly gas consumption

Figure 6 Monthly electric and gas consumption & costs

5. CONCLUSION

The air leakage rate for newly constructed apartments in South Korea were measured and analyzed to improve the airtightness on building envelopes. The airtigheteness measurements were conducted using the blower door test in accordance with ASTM E-779 and tracer gas method in accordance with ASTM E-741. To confirm the air leakage area, four parts, electric, mechanic-1, mechanic-2, and windows, were divided in the test unit.

The key findings are summarized as follows,

(1) The air leakage rate using a blower door was 0.7~1.0(ACH50) when all parts were sealed. On the other hand, the value was 1.6~2.7(ACH50) under unsealed condition and it can be considered that the unit is generally quite tight. The difference of the ACH50 in each unit between sealed and unsealed was about 1.0~1.7.

(2) To compare the results obtained by the blower door test and the tracer gas method was conducted. When all parts were unsealed, the infiltration rate was less than 0.1(ACH). Because air infiltration depends on the building envelope's airtightness and the pressure differential across the envelope, these differentials were caused by wind, stack effect, and operation of the building's mechanical equipment. It is necessary to study the effect of climatic conditions on these infiltration measurements.

(3) To find the most effective parts related to air leakage, the fan pressurization tests were also carried out. Gaps in the window frames and a mechanical parts 2(air system – ventilation for rooms, hood for kitchen, and exhaust duct line for the restroom) mainly affected the airtightness of the units. The entrance door was also largely influenced the air leakage rate.

(4) Generally, the airtightness of newly constructed apartments was quite tight. The air leakage rate was mainly affected in order by, *the entrance door, windows, mechanic 2 (air system), mechanic 1 (water system), and electric*.

By improving these parts, building energy can be saved and produce more comfortable environments.

In order to understand the influence of the airtightness in buildings, a scrutinization of the building elements and a large number of experiments are generally required. For the present study, the air leakage parts in residential buildings were analyzed and quantitative values related to the airtightness were obtained through the measurements. The data through the sudy can be used to develop the technology for materials and construction methods for improving the airtightness in buildings.

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DOE sensitivity analysis of urban morphology factors regarding solar irradiation on buildings envelope in the Brazilian tropical context

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ABSTR ACT

Faced with current energy constraints of fast-growing cities in developing countries, urban morphology has been pointed out as a pivotal issue on shifting to climate adapted urban environments. In this context, this paper addresses the two-fold sustainable energy challenge of tropical cities: the major potential in harnessing solar energy as renewable resource for local electricity production and the energy demand due to the undesirable solar heat gains in buildings. One first approach consists of measuring the size effect of urban morphological design variables for a particular climate context. Such an approach would allow prioritizing actions and hierarchizing important constrained factors to support urban design. A Design Of Experiments approach is then applied to this study. The DOE is a statistical technique that provides an objective measure of how design parameters are correlated and the effective contribution of each one at a given response of interest. This study proposes the use of the reduced factorial DOE method coupled to a Simplified Radiosity Algorithm (SRA) aiming to evaluating the irradiation availability on buildings envelope taking into account a large representative sample of contrasted urban geometry scenario. Through a case study for the tropical Brazilian city of Maceió, a set of energy-related morphological parameters are then assessed regarding the buildings envelope solar irradiation availability: floor area ratio, plot ratio, mean aspect, shape factor, verticality, contiguity, albedo, etc. Results indicate significant impact of the mean aspect, the buildings setbacks and the surface equivalent albedo. Establishing high values of mean aspect may represent a reduction of 130kWh/m^2.ano of solar irradiation on roofs and 146kWh/m^2.ano on West façade, while the increasing on the plot ratio may only represent a gain of 26kWh/m^2.ano on the irradiation of buildings roofs. The results also pointed out to important first order interaction effects between certain variables.

INTRODUCTION

Half of humanity is currently living in cities (PopulationReferenceBureau, 2009). In the Brazilian context, the speed of this urbanization process is increasing, with two side effects: a faster growth of the most populated cities without an effective urban development control, and a burst of the energy demand. In a perspective of urban sustainable development, built morphology has played a pivotal role on determining overall energy consumption in cities (Owens, 1986) (Droege, 2007) (Batty, 2008) (williams, Burton, & Jenks, 2000). By urban morphology we refer here to the particular shape and dimensions of the built environment and with the aggregations and configurations of building types. At this scale, the

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configurations of cities directly affect both outdoor and indoor climates and have a direct bearing on embodied and operational energy use (Ratti, Raydan, & Steemers, 2003).

Urban buildings account for a large part of the energy demand of urban areas. In Brazil, it represents a fraction of 47% (Ministério de Minas e Energia, 2010). Though many efforts have been recently employed at promoting energy efficiency in the built environment, they are mostly applied to individual building units (Ministério de Minas e Energia, 2010). However, few studies have recently attempted to quantify the effect of urban density and layouts on energy consumption of buildings (Martins, Bonhomme, & Adolphe, 2013) (Boyeur, Inard, & Musy, 2011) and on its potential of renewable energy production, such as solar energy (Compagnon, 2004) (Kampf, Montavon, Bunyesc, & Robinson, 2010) in developed countries. Yet, an extensive and objective approach that would allow quantifying the relative effect size of multiples urban form variables on solar energy potential in tropical climate is still less expressive.

In tropical climates, solar resource offers enormous potential for different applications. Besides indoor daylight, solar energy can be converted for local production of thermal and electrical energy. However, in these sunny regions, the building envelope solar heat gains can also produce extremely undesirable indoors thermal comfort conditions to users, which may consequently, increase electricity demand for space cooling. Since urban densification process produces great impact on the solar irradiation balance, especially on buildings envelopes, it is important to characterize the magnitude of this impact according to main morphologic and climatic parameters.

This paper aims at identifying the most sensitive urban morphological parameters from a set of well-known energy-related indicators on improving solar energy potential and illuminance level over building facades, in cities under tropical climate in Brazil.

METHOD

The methodology follows a systematic procedure:

1. Firstly, a set of known energy-related urban morphological parameters is identified within specific literature. A statistical hypothesis is established which consists of assuming that all variables considered are relevants to the response variables under investigation (solar energy and daylighting potential).
2. Through a Design of Experiments (DOE) methodology, all urban morphological parameters are put together on a simplified urban model, compounding a set of diverse and contrasted urban scenarios. For that, a fractional factorial method is applied which allows elaborating statisticaly representative and non-redudant scenarios. The scenarios are then assessed regarding the irradiation and illuminance availability on their surfaces using a Simplified Radiosity Algorithm (SRA), with an application for the tropical context of the city of Maceió, situated in the Northeast of Brazil.
3. The results obtained are assessed through a statistic hypothesis test, which allows identifying the effect size of each variable on the response.

To conduct the above described methodology we coupled two computer programs: Citysim (Robinson, 2005), for the dynamic simulations of the solar irradiation availability of urban models, and modeFRONTIER® (ESTECO, 2013) for the DOE analysis.

For application of the proposed method, a case study was conducted for Maceió. As many Brazilian cities, Maceió has experienced during recent decades, rapid and intensive urbanization, but frequently without any effective control, particularly regarding environmental and infrastructural concerns. This kind of urbanization process has been gradually modifying local urban climate, which affects thermal comfort conditions (outdoors and indoors) as well as building energy demand.

Regarding local climatic particularities, the radiant energy presents very slight annual and seasonal variations, demonstrating its vast natural potential to engage new energy strategies. Nevertheless, we must also bear in mind, that in tropical regions, we have equally constantly high air temperature and high levels of relative air humidity, all year long. Then, enhancing radiation incidence on buildings may impose itself as an important and undesirable heating source, undermining comfort conditions that might also cause increase on energy consumption. Thus, revising current urban building control parameters, notably regarding its morphology, might play decisive role on addressing adequately this conflicting problematic.

DESIGN OF EXPERIMENTS (DOE)

The urban morphology comprises a large set of factors that plays important role on modifying urban climate and, consequently, the potential energy demand and supply in cities. In order to better understand the impact of these factors, parametric studies are often undertaken. Though, such studies often involve innumerous individual cases. Carrying out dynamic computer simulation of several and sometimes random cases may be an extremely time consuming activity with great computational effort associated.

An efficient alternative for that matter is the DOE methodology for parametric sensitivity analysis (Montgomery, 2001). The original use of DOE refers to methods used to obtain the most relevant qualitative information from a database of experiments by making the smallest possible number of experiments. According to such methods, experiments are planned in a way that redundant observations can be eliminated without any loss of representativeness, reducing the number of tests in order to provide information on the major interactions between the variables (Kleijnen, 2005) (Montgomery, 2001). Statistical DOE is usually part of the optimization process as it can be useful to carry out a preliminary exploration of the design space while establishing the relationship between the measured responses of interest and the process factors (design variables) being studied.

To properly conduct the DOE methodology, we start by identifying the input variables and the response parameters of interest on which the sensitivity will be assessed. For each input variable, a number of levels are defined that represent the range of desired effect on each variable. Experiments are then defined on a specific experimental design method, which defines each input parameter for each run of the experimental tests. Responses are assessed, observing the possible differences between groups of the input changes. These differences are then attributed to individual input variables acting alone (main effect) or in combination with another input variable (interaction effect). Finally, since the designed experiments are generated on the basis of statistical theory, confidence in the results obtained is defined by means of statistical hypothesis test.

Definition of urban morphological parameters (input design variables)

To define the key morphological parameters, the methodology developed by Adolphe *et al*. (2002) was applied. The author's proposal came from a simplified spatial modeling of the urban morphology, resulting in the definition of a set of energy-related morphological indicators for the urban fabric. A system of morphological indicators is essential to support planners and decision makers controlling urban form and the intensity of urban development. The major urban design parameters used in this morphological approach was, among others: Compactness, Contiguity, Aspect Ratio (AR), and Shape Factor (SF). In addition to those, we also considered in this study the well known: Plot Ratio (PR) and Floor Area Ratio (FAR). The climatic and morphological hypotheses, methodological procedures of development of this system of indicators as well as their full description can be found in Adolphe *et al*. (2002).

Fractional factorial method

In order to determine whether any change in design variables affects the results of the irradiation and daylight levels on surfaces, the most intuitive approach would be to try all possible combinations of settings. But the number of necessary experimental runs increases geometrically with the number of variables. Instead, a fractional factorial design method defines experimental sets consisting of a carefully chosen fraction of the experiments defined by a full factorial method. Such fraction is chosen so as to exploit the sparsity-of-effects principle capable to provide representative information about the most important effects related to the problem, while using a reduced fraction of the effort of a full factorial design in terms of experimental runs and computational resources.

A two-level design is usually enough for evaluating factors effect in many scientific problems (Montgomery, 2001). Experimenters evaluating process changes are often interested in the factor effect directions that lead to process improvement. A half-fraction of the 2^k designs is usually adopted as it involves running only half of the treatments of the full factorial design. For this study, comprising fourteen urban design variables (see Table 1), a full factorial design would define 16384 experiments (2^{14}). A half-fraction of this design would require 8192 test runs.

Statistical hypothesis analysis

To verify the significance of the design variables and their interaction on response parameters, a statistical hypothesis test is applied, by using data obtained from a controlled experimental run. In this study the data are obtained from dynamic simulations of the surface irradiation response of different built urban geometric models. Each experiment defined by fractional factorial method represents a specific urban configuration. A result is called statistically significant if it is unlikely to have occurred only by chance, according to a pre-determined threshold probability, the significance level. Statistical hypotheses testing and confidence interval estimation of parameters are the fundamental methods used for comparative experiment assessment. To perform such analysis, one has to formulate the hypothesis to be tested: the null (that one wants to deny) and alternative hypotheses. We state that the fourteen urban typo-morphological factors investigated represent significant impact on the irradiation balance and illuminance level on all built surfaces in any urban scene under the tropical climatic context studied.

The decision of rejecting or not the null hypothesis can be taken based on a confidence interval. Here we consider a confidence interval of 95%, corresponding to significance equal to 0.05. In order to assess the significance of the design variables effect on the response parameters a Student t-test is here considered.

The DOE simplified urban model description

For the sensitivity analysis of the morphological factors considered, we use a simplified urban model, from which it is possible to establish contrasted variations following the statistical analysis method. An urban model composed of 25 buildings is considered, each one ranging variations in all dimensions (width, thickness and height) and the space between buildings, as shown in Figure 1 below. From these basic variables it is possible to assess variations of the set all of our energy-related morphological factors. In addition, some key features of the building envelopes are also assessed, such as: facades glazing ratio, shortwave reflectance, U-value, glazing ratio, glazing G-value, and glazing U-value. In this analysis, a wide range of possible lower and upper values for each variable is considered (Table 1), independently of good practices or urban codes. Composing the statistical search space as completely as possible allows better measuring the sensitivity of each factor on the variable responses of interest, while avoiding bias or redundancy on the results.

In this study, two response variables are considered: the shortwave irradiation and the illuminance level on building envelope. Annual statistics are considered as time base scale of analysis since in some tropical regions, as in Maceió, seasonal variation in climate can be relatively slight. Concerning the spatial resolution, we carry out analysis of the urban form on the neighborhood scale (up to 500m x 500m) and its influence on the urban block of nine individual building envelopes (see Figure 1).

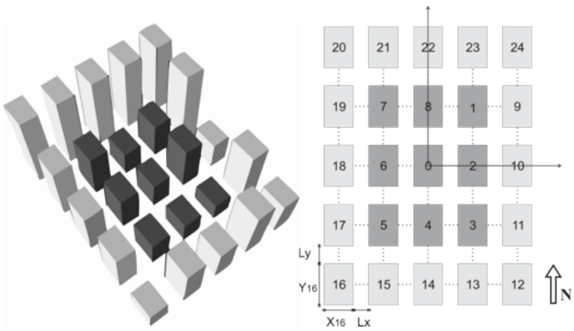

Figure 1 Simplified urban model used on the statistical study.

Table 1 range of possible values (upper and lower levels) of urban main factors defining the urban scene considered.

Height	Width (X)	Thickness (Y)	Dist. between buildings	Glazing G-value	Glazing U-value	Facades U-value	Glazing ratio	Floor area ratio	Plot ratio	Shape factor	Verticality	AR	Albedo
m	m	m	m	/	W/m²K	W/m²K	%	/	/	/	/	/	/
3	4	4	3	0.1	1.3	0.7	0.2	0.3	0.05	0.4	0.01	0.6	0.1
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
50	40	40	30	0.9	5.0	4.8	0.9	10.3	0.85	1.0	0.8	3.9	0.9

In order to measure the irradiation and daylight availability on buildings surfaces, in the urban district scale, we have chosen to employ a Simplified Radiosity Algorithm (SRA) into the Citysim code. The SRA consists of a coupling of well-known models that allows predicting radiant energy flux reaching any shape of building, accounting for the effects of urban obstructions in reducing direct, anisotropic diffuse and contributing reflected radiation.

Similarly, the model estimates daylight, considering the effects of obstructions in reducing sky and contributing reflected illumination. SRA is currently one of the few algorithms that allows, on one hand, robustness on modeling the complex solar behavior in the urban district scale of hundred of buildings and, on the other, fast computer simulation. However, to meet this trade-off between robustness and fast calculation, the SRA relies on two key simplifications: all urban surfaces are Lambertian (ideal diffusely reflecting surfaces) and the average radiance of an occluded region of a sky patch is equal to that calculated at the center of the main (largest) occluding surface within this patch. The accuracy of this algorithm was tested comparing results, for identical urban scenarios, with a referential ray-tracing program, RADIANCE, reaching good agreement. The detailed description of the SRA is thoroughly documented in Robinson (2005). The input variables to be provided into the computer model consist of a set of climatic (complete local climatic year, geometric (3D buidlings) and thermo-physical data and parameter specifications (e.g. albedo, glazing ratio, glazing G-value, envelope U-value). The output variables considered are the yearly solar irradiation [kWh (m^{-2} year)] (direct, diffuse and reflected contributions) and yearly mean illuminance [lx] on buildings facades.

RESULTS AND DISCUSSIONS

From the statistical overall student test, the *aspect ratio (AR)*, the *distance between buildings (SW)* in both axes (North-South and East-West) and the *albedo* are identified as the factors producing most relevant effects on the modification of the shortwave irradiation as well as on the illuminance levels of buildings surfaces, but in different ways. The *albedo* and the *AR* account together with more than 50% of overall impact on roofs, with major participation of the *AR* (27%). Regarding building vertical surfaces, the overall impact of these design variables may reach 75% for south facade. These variables relevance has already been highlighted before, concerning the solar energy potential and energy consumption in cities (Montavon, 2010), but their magnitude and relative importance, notably in the tropical climate environments, has not yet been measured and it may support prioritizing certain decisions.

In order to identify and qualify the intensity of these effects, the factors are analyzed individually regarding the both responses of interest (Figures 2 and 3).

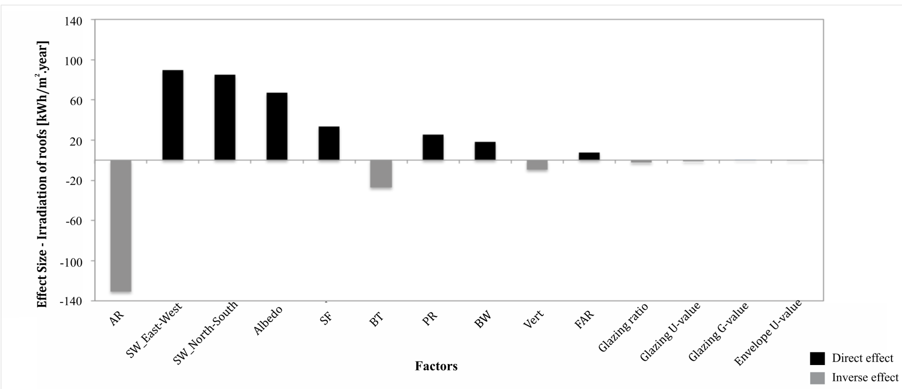

Figure 2 Effect size of all factors regarding solar irradiation on building roof surface.

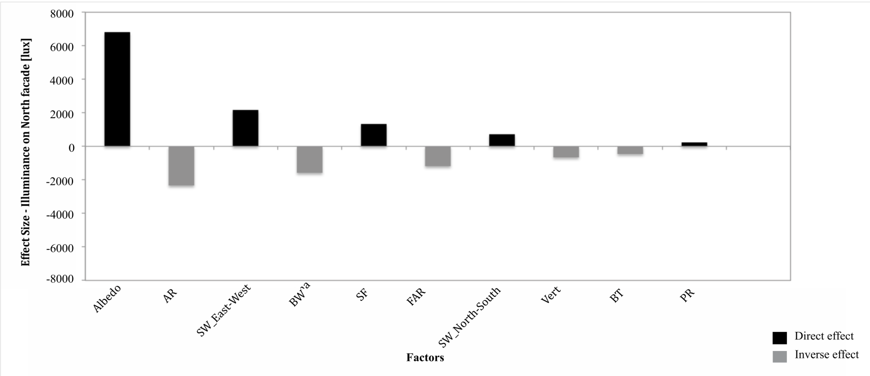

Figure 3 Effect size of all factors regarding illuminance response on building North facade.

As stated earlier, the null hypothesis indicates that the variable does not produce significant effect on the response. The Tables 2-4 below present the results of the significant data obtained to the hypothesis tests regarding the effect size of the solar irradiation on roofs and facades. The tables present the effect size, significance, and *t*-student statistic test. Effect size indicates the relationship between the factor and the response variable: negative values indicate that the relationship is inverse.

The results seem consistent regarding both that radiant energy and illuminance behavior expected in urban configurations. The *albedo* presents an important direct influence on the responses. Meaning, the higher the albedo of an urban surface (higher reflectance), the greater will be the exchange of shortwave irradiation between them (greater reflections) and greater will also be the illuminance level found on building facades. For the *AR* (building height to street width ratio), it indicates an inverse size effect, it means that the greater the height of the buildings compared to the distance between them, greater the shadows casted on each other's roof and facades, which may reduce the global response in terms of radiation incidence and daylight received on building surfaces. Establishing high values of mean aspect may represent a reduction of 130kWh/m^2.ano of solar irradiation on roofs and 143kWh/m^2.ano on West façade, while the increasing on the plot ratio may only represent a gain of 26kWh/m^2.ano on the irradiation of buildings roofs (Tables 2).

Regarding the *distance between buildings (SW)* over the two street axes (North-South and East-West), they present important direct effect on the response parameters. The more spaced out are the buildings, greater will be the availability of irradiation and illuminance level on building surfaces due to less sun and sky obstruction. Among other influent variables, the Shape Factor (SF) presented a direct effect. This could be explained by the influence of vertical surfaces inter-reflections. The larger the surface of envelope in relation to the built volume, the greater could be the level of illuminance found on facades. The same behavior is identified for the irradiation response on facades, which may also represent greater solar heat gains to buildings.

According to the confidence interval adopted in this study (of 95%), seven typo-morphological factors could be highlighted regarding their relevant influence on the irradiation response parameter, both on roof and facades: *aspect ratio,* the *distance between buildings, albedo, shape factor, thickness* of buildings, the *floor area ratio* and the *plot ratio* (Tables 2). Regarding the illuminance response on the four oriented facades, the five most significant urban morphology parameters are: *albedo, aspect ratio, distance between buildings, building width* and *shape factor* (Table 3).

Table 2 significance test results regarding solar irradiation on building's roof and West façade.

Factors	***Solar irradiation on Roofs*** Effect size (kWh/m^2.ano)	Significance	*t*-Student	***Solar irradiation on facades*** Effect size (kWh/m^2.ano)	Significance	*t*-Student
Aspect ratio	-130.30	0.00	9.26	-143.97	0.00	4.13
Distance between buildings (E-W axe)	89.00	0.00	8.38	54.59	0.03	1.85
Distance between buildings (N-S axe)	84.60	0.00	7.84	129.06	0.00	4.55
Albedo	67.60	0.00	5.93	413.36	0.00	28.95
Shape factor	33.10	0.00	2.49	77.60	0.00	2.34
Thickness	-26.70	0.02	2.23	-92.29	0.00	3.17
Plot ratio	25.80	0.02	2.23	-58.1	0.02	2.05
Floor Area Ratio	8.2	0.33	0.43	-74.12	0.02	1.95

Table 3 significance test results regarding the illuminance level on buildings North facade.

Factors	Effect size (lx)	Significance	*t*-Student
Albedo	6817.85	0.00	25.76
Aspect factor	-2331.10	0.00	3.30
Distance between buildings (E-W)	2173.08	0.00	4.48
Building width	-1577.27	0.00	3.19
Shape factor	1337.91	0.00	2.96

However, it is necessary to evaluate the interaction effect between design variables before any conclusion is taken. For that purpose, a half normal plot of effects, based on the absolute value of the effect estimated against cumulative normal probabilities, is performed (Montgomery, 2001). A normal plot is useful to distinguish between the most significant (upper-right) and less significant (lower-left) effects, considering both main and first order interaction effects. The existence of a strong interaction means that the effect of a variable depends on the response of another one. In the graphs below (Figures 4a and 4b), black squares represent the direct effect on the response, that is, when the value of the variable increases, the response parameter also increases. Likewise, the inverse effect in the response is represented by the gray squares.

From the figure 4a below, it is possible to verify similar main effects as in the previous analysis, regarding the great relevance of the *aspect ratio* and *distance between buildings* (SW in both axes) on the building roof surface. In addition, it is also possible to verify the important interaction effect between these variables and the *floor area ratio (FAR)*. These results seem reliable since the *floor area ratio* represents the relation between the building footprint (and consequently the roof area availability) and the number of floors, which have a significant direct effect on the irradiation level on roofs. The greater the built surface, greater is the received radiant energy.

If we examine the results for facades (Figure 4b), both for irradiation and illumination levels, we can also find the important main effect of the *albedo*, but equally the interaction effects between it and other morphological factors which individually presented negligible influence in the previous analysis – as *verticality, floor area ratio, plot ratio*. If the *albedo* individually represents an important direct main effect, when it interacts with other important morphologic variables, the former impose major influence and the effect turns out to be inversed. These variables present superior weight on the interaction, which means that, independent of the albedo variation; higher density will lead to lower irradiation and illuminance availability on vertical building surfaces. This result can be attributed to the main impact of sky obstruction by surrounding buildings. All four facades presented similar results, except for the major influence of orientation-related factors, such as thickness and width, which depending on the facade orientation they will present different values.

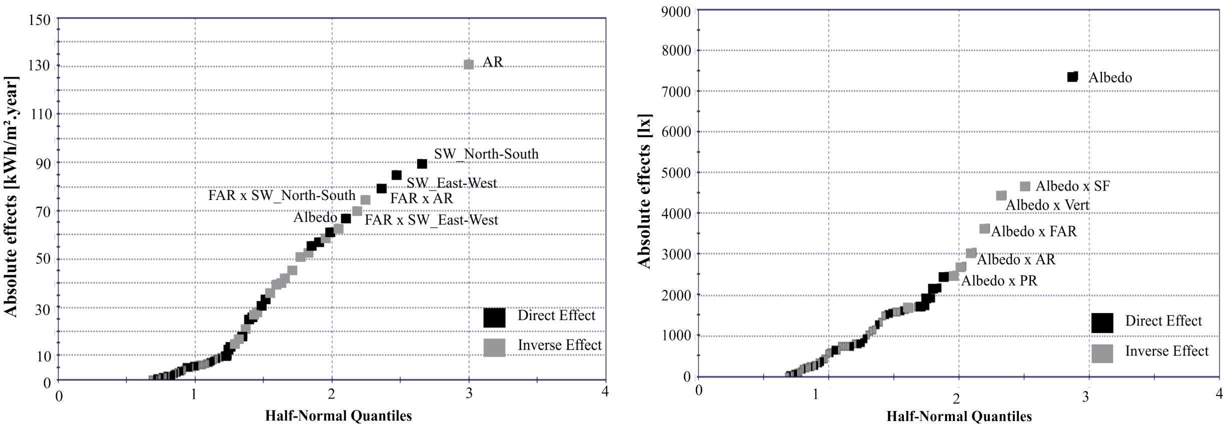

Figure 4 Half-normal-plot charts with respect to the irradiation level on roofs (a) and building North façade (b).

CONCLUSION

Given the complexity of the urban morphology and the interrelationship between different built (urban and architectural) scales, this work is motivated by the limited knowledge available about objective effect size of urban morphological variables in tropical climate contexts.

Statistical study on the sensitivity of the main morphological factors provided important information about their contribution on the building responses. This significance tests allowed hierarchizing factors by their importance on improving solar energy potential on roofs and solar control over vertical facades.

One such interdisciplinary approach can be very relevant by allowing to define efficiently and objectively sets of parameters that could respond to a reasonable trade-off between different conflicting measures of efficiency while preserving a set of important and context-related criteria. This methodology leads to more comprehensive set of indicators to be applied in a larger scale as for master plan proposals, but may also allow punctual interventions on a rapid changing district. In that sense, the current study could also be used as an influential tool to support prioritizing actions concerning urban regulation guidelines and practicing.

ACKNOWLEDGMENTS

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Session 4E : Material technology

PLEA2014: Day 2, Wednesday, December 17
8:30 - 10:10, Faith - Knowledge Consortium of Gujarat

Analytical Computation of Thermal Response Characteristics of Homogeneous and Composite Walls of Building and Insulating Materials Used In India

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ABSTRACT

Climate responsive building design involves the study of the thermal response of building and insulating materials exposed to periodic changes of environmental conditions. For calculation of such unsteady thermal characteristics, one dimensional heat flow diffusion equation under periodic boundary conditions was solved using matrix algebra and thermal characteristics like admittance, transmittance, decrement factor, time lag, surface factor and surface factor time lags were calculated for homogeneous and composite walls. In this study, ten building and ten insulating materials were studied. Optimum wall thicknesses of building and insulating materials were calculated. From the results, it was concluded that mud phuska and coconut pitch are the most recommended homogeneous building and insulation materials respectively, among studied building and insulating materials, from lower decrement factor and higher time lag point of view. It is found that the insulation materials are highly responsive to short wave radiation than that of building materials. From the study, ultimately it is concluded that Burnt brick composite walls with Coconut pitch insulation is the best composite wall among all studied walls for reduced cooling loads and the most energy efficient building construction.

INTRODUCTION

The building sector represents about 33% of power consumption in India, with the commercial sector and residential sector accounting for 8% and 25% respectively (ECBC, 2009). Buildings are also responsible for carbon dioxide emissions with a consequential impact on global warming. The building envelope is the physical barrier that separates the interior of the building from the outdoor environment. The purpose of the envelope of a building is to act as a passive climate modifier to help in maintaining an indoor environment more suitable for habitation than the outdoors.

Previously, The EN ISO 13786:2007 procedure has been compared with fast Fourier transform analysis (Gasparellaa et al., 2011). The effects of thermo physical properties and thickness of a wall of a building on time lag and decrement factor have been investigated using crank Nicolson method by many researchers (Asan et al., 1998). Numerical computations of time lag and decrement factor for different building materials were also investigated (Asan, 2006) and also Effects of Wall’s insulation thickness and position on time lag and decrement factor were studied in detail (Asan, 1998). The present study focuses on the cyclic response admittance method to calculate unsteady state thermal characteristics of the homogeneous and composite walls for more energy efficient building design.

ANALYTICAL SOLUTION FOR WALL THERMAL RESPONSE CHARACTERISTICS

The admittance procedure is used (CIBSE, 2006) to calculate the unsteady state parameter values which use matrices to simplify the temperature and energy cycles for a composite building fabric element that is subjected to sinusoidal temperature variations at the sol–air node. The temperature distribution in a homogeneous wall subjected to one dimensional heat flow is given by the diffusion equation,

$$\frac{\partial^2 T(X,t)}{\partial X^2} = \frac{\rho Cp}{k}\frac{\partial T(X,t)}{\partial t} \qquad (1)$$

Fourier equation can be written as shown in Equation 2.

$$T(x,t) = [Asinh(\gamma x + j\gamma x) + Bcosh(\gamma x + j\gamma x)]exp(j2\pi t/P) \qquad (2)$$

Where, $\gamma = \sqrt{\pi\rho c_p/\lambda P}$

When the conducting medium finite thickness slab X, temperature and flows at the two surfaces are considered then the above equation can be written as,

$$\begin{bmatrix} T_0 \\ q_0 \end{bmatrix} = \begin{bmatrix} cosh(z+jz) & \left(sinh(z+jz)\right)/a \\ \left(sinh(z+jz)\right)\times a & cosh(z+jz) \end{bmatrix} \begin{bmatrix} T_1 \\ q_1 \end{bmatrix} \qquad (3)$$

Where, cyclic thickness $(z) = \sqrt{\pi\rho c_p X^2/\lambda P} = \sqrt{\pi cr/P}$ and Characteristic admittance of slab$(a) = \sqrt{j2\pi\lambda\rho c_p/P} = \sqrt{j2\pi c/rP}$.

Transmission matrix of single layer can be written as (Davies, 2004),

$$\begin{bmatrix} A+jB & (C+jD)/a \\ (-D+jC).a & A+jB \end{bmatrix} \qquad (4)$$

Where, constants $A = \cosh(z)\cos(z)$,$B = \sinh(z)\sin(z)$, $C = [\cosh(z)\sin(z) + \sinh(z)\cos(z)]/\sqrt{2}$ and $D = [\cosh(z)\sin(z) - \sinh(z)\cos(z)]/\sqrt{2}$.

Transmission matrix of surface internal (R_{si}) and external (R_{se}) film resistances can be written as,

$$Msi = \begin{bmatrix} 1 & -R_{si} \\ 0 & 1 \end{bmatrix} \; and \; Mse = \begin{bmatrix} 1 & -R_{se} \\ 0 & 1 \end{bmatrix} \qquad (5)$$

Transmission matrix for composite wall can be written as,

$$\begin{bmatrix} T_i \\ q_i \end{bmatrix} = \begin{bmatrix} 1 & -R_{si} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} x_1 & x_2 \\ x_3 & x_1 \end{bmatrix}\begin{bmatrix} y_1 & y_2 \\ y_3 & y_1 \end{bmatrix}\ldots.\begin{bmatrix} 1 & -R_{se} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} T_e \\ q_e \end{bmatrix} \qquad (6)$$

Where, x and y represent number of layers of the wall.

Transmission matrix can be further reduced as follows,

$$\begin{bmatrix} T_i \\ q_i \end{bmatrix} = \begin{bmatrix} E_1 & E_2 \\ E_3 & E_4 \end{bmatrix}\begin{bmatrix} T_e \\ q_e \end{bmatrix} \qquad (7)$$

From the above matrices, the following unsteady state thermal characteristics can be calculated.

Thermal Transmittance (U)

This is the steady state heat flow through the element per unit degree of temperature difference between the internal and external environmental temperatures per unit area.

Thermal Admittance (Y)

This is the amount of energy leaving the internal surface of the element into the room per unit degree of temperature swing.

$$Y = \left|\left(\frac{q_i}{\theta i}\right)_{T_{e=0}}\right| = \left|-\frac{E_1}{E_2}\right| \qquad (8)$$

Time lead for thermal admittance (ω)

It is the time difference between the timing of the peak heat flow at the internal surface and timing of the peak internal temperature.

$$\omega = \frac{12}{\pi} arctan\left(\frac{Im(\frac{E_1}{E_2})}{Re(\frac{E_1}{E_2})}\right) \qquad (9)$$

Decrement factor (f)

It is the attenuation of sinusoidal wave as it progresses through the wall.

$$f = \left|-\frac{1}{UE_2}\right| \qquad (10)$$

Decrement delay (ϕ)

It is the time lag between the timing of the internal temperature peak and the peak heat flow out of the external surface.

$$\phi = \frac{12}{\pi} arctan\left(\frac{Im(-\frac{1}{UE_2})}{Re(-\frac{1}{UE_2})}\right) \qquad (11)$$

Surface factor (F)

It is the ratio of the swing in heat flow from the internal surface of the element to the swing in heat flow received at the internal surface of the element.

$$F = \mid 1 - R_{si}\left(-\frac{E_1}{E_2}\right) \mid \tag{12}$$

Time lag for the surface factor (ψ)

It is the time lag between the timing of the peak heat flow entering the surface and peak heat flow leaving the surface into the room.

$$\Psi = \frac{12}{\pi} arctan\left(\frac{Im(1 - R_{si}\left(-\frac{E_1}{E_2}\right))}{Re(1 - R_{si}\left(-\frac{E_1}{E_2}\right))}\right) \tag{13}$$

Optimum wall thickness (d)

It is the thickness of the wall at which the wall has its maximum heat storage.

$$d = 1.18251\sqrt{2\alpha/\omega} \tag{14}$$

UNSTEADY STATE THERMAL CHARACTERISTICS OF HOMOGENEOUS AND COMPOSITE WALLS

Table 1 shows the thermo-physical properties of Building materials at 50^{o}C and Table 2 shows the thermo-physical properties of Insulating materials considered for the study at 50^{o}C (SP:41, 1987). Ten building and ten insulation materials were selected for the study from Indian standard guide for heat insulation of non industrial buildings as per IS code 3792-1978. The methods used to measure thermal conductivities (k) of building and insulating materials in IS code are guarded hot plate method and ASTM heat flow methods (IS 3792, 1978). Thermal properties k, Cp and α represent thermal conductivity specific heat capacity and thermal diffusivity respectively. ρ is the density of material.

Table 1. Thermo Physical Properties of Building materials at 50^{o}C (*Experimental values)

Building material	Code	k (W/mK)	ρ (kg/m^3)	Cp (J/kgK)	α x10^{-7} (m^2/s)
Malabar Laterite Stone*	BM1	1.3698	1000	1926.1	7.11
Madras Black clay	BM2	0.735	1899	880	4.39
Indore Black clay	BM3	0.606	1683	880	4.09
Slate	BM4	1.72	2750	840	7.44
Burnt brick	BM5	0.811	1820	880	5.06
Mud brick	BM6	0.75	1731	880	4.92
Reinforced brick	BM7	1.10	1920	840	6.82
Brick tile	BM8	0.798	1892	880	4.79
Mud phuska	BM9	0.519	1622	880	3.63
Cinder concrete	BM10	0.686	1406	840	5.80
Plaster*	P	0.57	1300	1000	4.38

Table 2. Thermo Physical Properties of Insulating materials at 50^{o}C

Insulating material	Code	k (W/mK)	ρ (kg/m^3)	Cp (J/kgK)	α x10^{-7} (m^2/s)
Saw dust	IM1	0.051	188	1000	2.71
Rice husk	IM2	0.051	120	1000	4.25
Coir board	IM3	0.038	97	1000	3.91
Jute felt	IM4	0.042	291	880	1.64
Jute fiber	IM5	0.067	329	1090	1.86
Coconut pitch insulation	IM6	0.06	520	1090	1.05
Straw board	IM7	0.057	310	1300	1.41
Asbestos fiber	IM8	0.06	640	840	1.11
Wall board	IM9	0.047	262	1260	1.42
Chip board	IM10	0.067	432	1260	1.23

The computer program was developed and used to calculate the unsteady state thermal characteristics of homogeneous and composite walls. Figure 1 shows the images of building and insulating materials considered for the study. The building materials are coded from BM1 to BM10 whereas the insulating materials are coded from IM1 to IM10. Plaster was represented by code P. Thermal properties of Laterite stone (BM1) and plaster (P) were measured experimentally using ISO 22007-2 transient plane source method at K-Analys AB, Sweden. Table 3 and Table 4 show the unsteady state thermal characteristics of building and insulating materials, respectively. The nominal thickness of the homogeneous wall was taken as 0.2m.

Table 3. Unsteady state thermal characteristics of Building materials

Code	U (W/m^2K)	f	Φ (h)	Y (W/m^2K)	ω (h)	F	Ψ (h)
BM1	3.16	0.56	5.44	5.26	1.12	0.38	1.94
BM2	2.26	0.51	6.39	4.58	1.39	0.48	1.66
BM3	2.00	0.52	6.43	4.26	1.52	0.52	1.53
BM4	3.49	0.52	5.63	5.63	0.97	0.33	2.09
BM5	2.40	0.54	5.95	4.61	1.38	0.47	1.68
BM6	2.29	0.55	5.95	4.48	1.43	0.49	1.63
BM7	2.84	0.60	5.26	4.87	1.27	0.43	1.80
BM8	2.37	0.52	6.15	4.65	1.37	0.47	1.69
BM9	1.80	0.50	6.74	4.07	1.58	0.55	1.46
BM10	2.16	0.64	5.17	4.07	1.59	0.54	1.49

Table 4. Unsteady state thermal characteristics of Insulating materials

Code	U (W/m^2K)	f	Φ (h)	Y (W/m^2K)	ω (h)	F	Ψ (h)
IM1	0.24	0.61	6.17	0.77	2.79	0.92	0.27
IM2	0.24	0.77	4.30	0.60	2.88	0.94	0.22
IM3	0.18	0.76	4.53	0.48	2.93	0.95	0.17
IM4	0.20	0.40	8.75	0.81	2.71	0.92	0.28
IM5	0.31	0.43	8.20	1.17	2.59	0.88	0.41
IM6	0.28	0.22	11.80	1.36	2.51	0.86	0.47
IM7	0.27	0.33	9.78	1.15	2.59	0.88	0.40
IM8	0.28	0.24	11.41	1.33	2.52	0.87	0.46
IM9	0.22	0.33	9.66	0.96	2.65	0.90	0.33
IM10	0.31	0.27	10.79	1.40	2.50	0.86	0.49

Table 5. Configuration of Composite walls

Configuration	Thickness (m)
C.W-1	0.015 P + 0.1 BM1 + 0.02 IM6 + 0.1 BM1 + 0.015 P
C.W-2	0.015 P + 0.1 BM5 + 0.02 IM6 + 0.1 BM5 + 0.015 P
C.W-3	0.015 P + 0.1 BM6 + 0.02 IM6 + 0.1 BM6 + 0.015 P
C.W-4	0.015 P + 0.1 BM7 + 0.02 IM6 + 0.1 BM7 + 0.015 P
C.W-5	0.015 P + 0.1 BM10 + 0.02 IM6 + 0.1 BM10 + 0.015 P

One dimensional diffusion equation was solved under periodic boundary conditions using matrix algebra. The transmission matrix for a homogeneous wall was shown by Eqs.(4). The transmission matrix for internal and external surface resistances is shown by Eqs. (5). In the present study, the walls are considered as external walls therefore external and internal surface resistances selected are 0.04 m^2 K/W and 0.13 m^2 K/W respectively as per CIBSE standards. Among all the studied insulating materials, coconut pitch insulation (IM6) is found to be energy efficient from lowest decrement factor (0.22) and highest time lag (11.80h) point of view. Hence this insulation is used to frame the composite walls with the most commonly used building materials in South India. Five composite walls are coded from C.W-1 to C.W-5. Figure 2 shows the configuration of composite wall. Table 5 shows the configuration of composite walls with thicknesses of plaster, building materials and Insulation materials. Table 6 shows the unsteady state thermal characteristics of composite walls.

Figure 1 Images of homogeneous materials (a.) Images of building materials (b.) Images of insulating materials

Table 6. Unsteady state thermal characteristics of Composite walls

Code	U (W/m^2K)	f	Φ (h)	Y (W/m^2K)	ω (h)	F	Ψ (h)
C.W-1	1.42	0.30	8.87	5.11	1.36	0.44	2.10
C.W-2	1.24	0.32	9.10	4.66	1.55	0.50	1.89
C.W-3	1.21	0.33	9.05	4.57	1.60	0.51	1.86
C.W-4	1.35	0.35	8.50	4.85	1.52	0.48	2.02
C.W-5	1.18	0.42	8.09	4.30	1.83	0.56	1.81

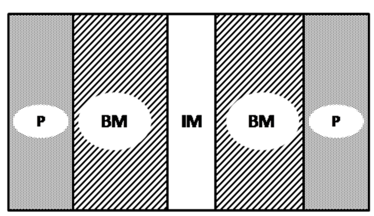


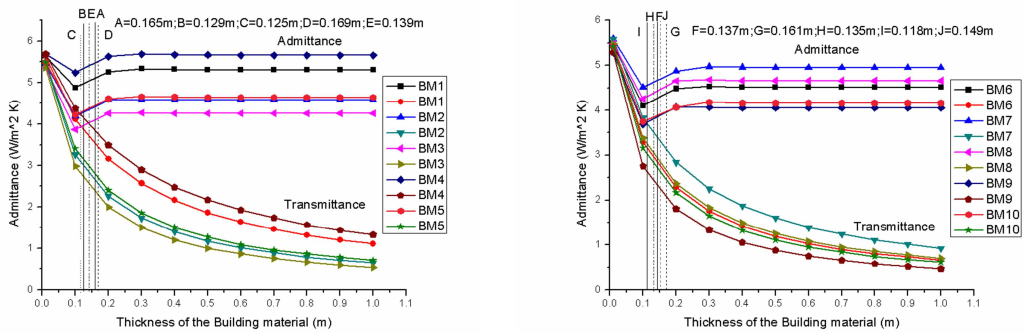
Figure 2 Configuration of composite wall (BM: Building material, IM: Insulating material, P: Plaster)

RESULTS AND DISCUSSIONS

Wall thickness greater than optimum does not give any additional energy storage benefits rather it reduces energy storage. The physical explanation given is that as heat stored in the fabric from previous days tries to escape, it meets with the current heat flow attempting to enter the fabric. Also, as d increases, after the peak Y value has been achieved, the thermal transmittance, U and volumetric heat capacity, continue to increase. Optimum wall thicknesses for building and insulating materials were calculated using Eqs. (14) (Magyari et al., 1998).

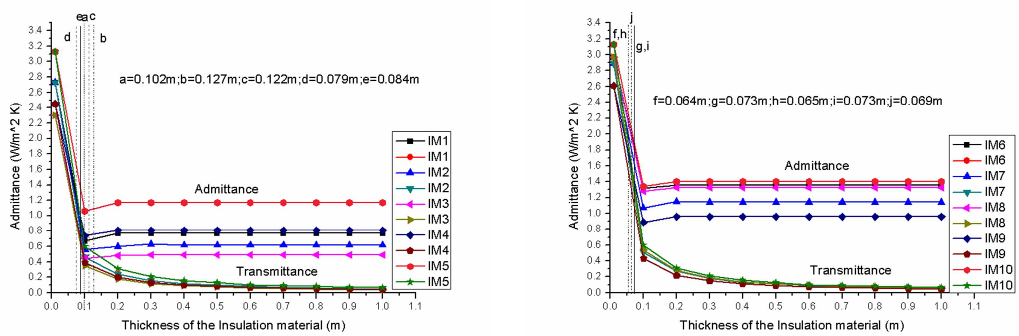
Figure 3 (a) and Figure 3 (b) show the variation of admittance and transmittance of the building materials with thickness. From figures, it is observed that for thin cross section fabrics admittance is equal to the transmittance. The values of A, B, C, D, E, F, G, H, I and J represent the optimum fabric thicknesses of the building materials from BM1 to BM10 respectively.

Figure 4 (a) and Figure 4 (b) show the variation of admittance and transmittance of the insulating materials with thickness. The values of a, b, c, d, e, f, g, h, i and j represent the optimum fabric thickness of the insulating materials from IM1 to IM10 respectively. The results show that among all the ten building materials studied, Mud phuska (BM9) has least optimum fabric thickness value I (0.118m) and slate (BM4) has higher optimum fabric thickness value D (0.169m). It is observed that among all the ten insulating materials studied, Coconut pitch insulation (IM6) material has least optimum fabric thickness value f (0.064m) and rice husk (IM2) has higher optimum fabric thickness value b (0.127m). At an optimum fabric thickness all the building and insulating materials have the maximum thermal heat capacity.



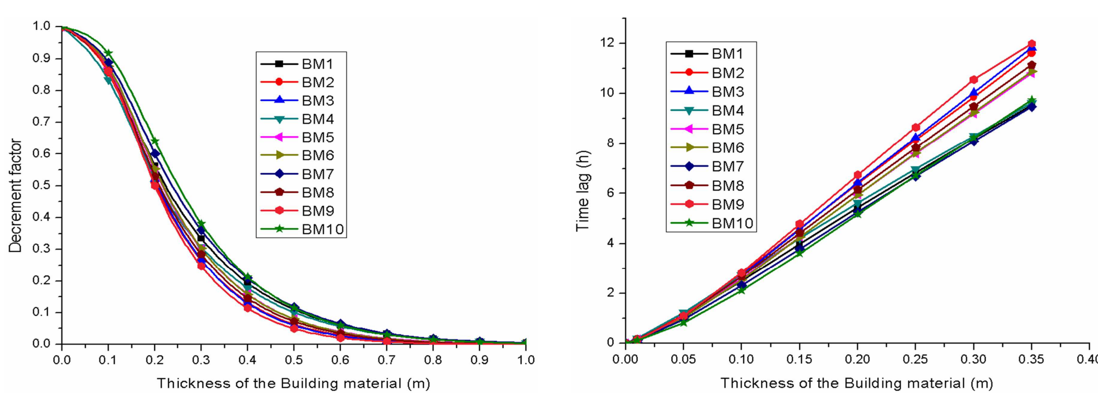
a.) b.)

Figure 3 (a) Optimum wall thickness of Building materials (BM1 to BM5) (b) Optimum wall thickness of Building materials (BM6 to BM10)



a.) b.)

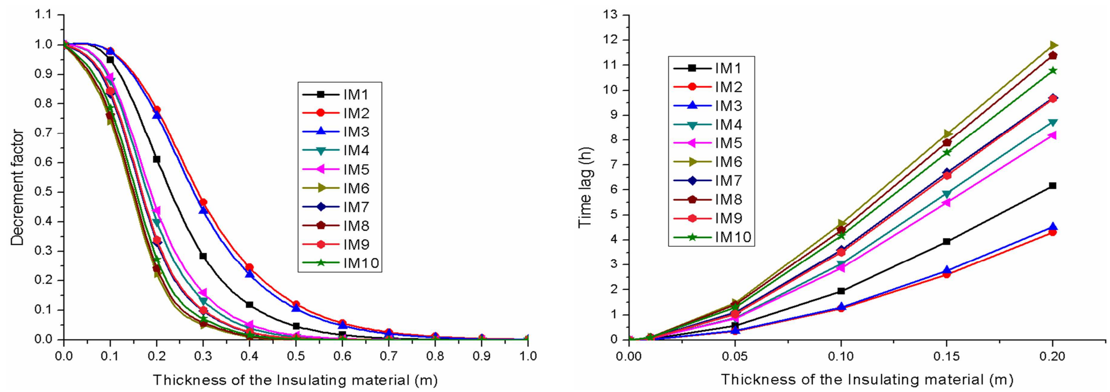
Figure 4 (a) Optimum wall thickness of Insulation materials (IM1 to IM5) (b) Optimum wall thickness of Insulation materials (IM6 to IM10)



a.) b.)

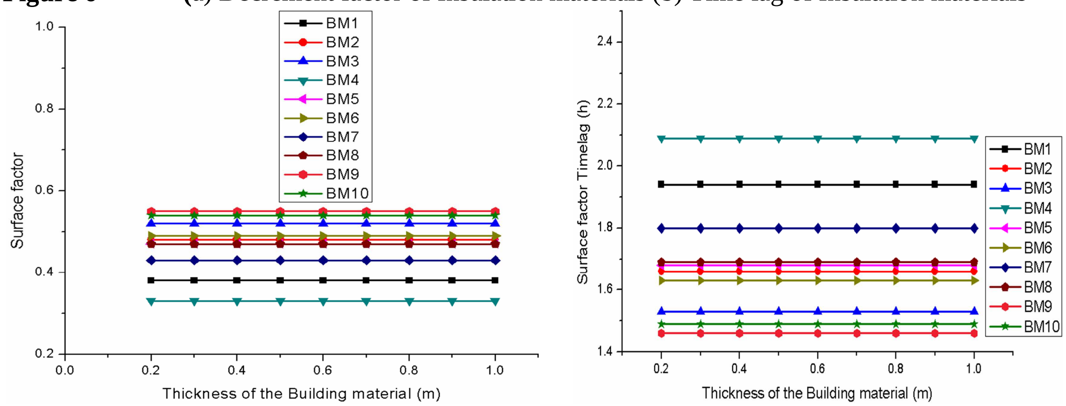
Figure 5 (a) Decrement factor of Building materials (b) Time lag of Building materials

Figure 5 and Figure 6 show the effects of wall thickness of the homogeneous building and insulating materials on the decrement factor and it's time lag respectively. The decrement factor of the building material decreases with an increase in the wall thickness. The time lag of building materials increases with an increase in the wall thickness. The smaller decrement factors and larger time lags are the more effective for the walls at suppressing temperature swings.



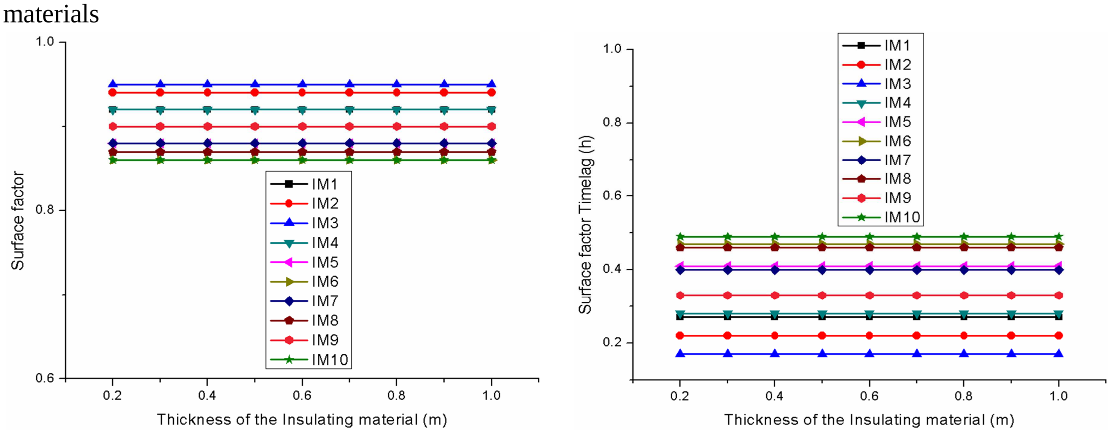
a.) b.)

Figure 6 (a) Decrement factor of Insulation materials (b) Time lag of Insulation materials



a.) b.)

Figure 7 (a) Surface factor of Building materials (b) Surface factor Time lag of Building materials



a.) b.)

Figure 8 (a) Surface factor of Insulation materials (b) Surface factor Time lag of Insulation materials

From Figure 5, it is apparent that mud phuska (BM9) has least decrement factor (0.5) and higher decrement time lags (6.74) whereas cinder concrete (BM10) has higher decrement factors and lower time lags among ten building materials studied. From Figure 6, it is observed that coconut pitch insulation (IM6) has least decrement factor (0.24) and higher decrement time lags (11.41) whereas rice husk (IM2) has higher decrement factors and lower time lags among ten insulating materials studied.

From Figure 7, it is observed that among ten studied building materials, slate (BM4) is slow responsive to short wave radiation due to its lowest surface factor (0.33) and highest surface factor time lags (2.09h) whereas mud phuska (BM9) is fast responsive to short wave radiation due to its higher surface factor (0.55) and lower surface factor time lags (1.46).

From Figure 8, it is noticed that among ten insulating materials studied, chip board insulation (IM10) is slow responsive to short wave radiation due to its low surface factor (0.86) and high surface factor time lags (0.49h) whereas coir board (IM3) is fast responsive to short wave radiation due to its higher surface factor (0.95) and lower surface factor time lags (0.17h). From Figure 7 and Figure 8, it is seen that surface factor and it's time lag do not depend on the thickness of the wall, but they depend only on thermal conductivity of the building or insulating material and the insulating materials are fast responsive to short wave radiation than the building materials due to their higher surface factors and lower surface factor time lags.

In practice, building walls are composite i.e., they are constructed with the combination of two or more homogeneous materials. Hence the best insulation material (coconut pitch (IM6)) among ten studied insulating materials was used as insulation material to frame composite walls with the most commonly used building materials (among ten building materials), Laterite stone (BM1), burnt bricks (BM5), mud bricks (BM6), reinforced brick (BM7) cinder concrete (BM10) and plaster (P). The insulation material was placed at the center of the composite wall as shown in Figure 2. From Table 6, it is observed that laterite stone composite walls (C.W-1) with Coconut pitch insulation (IM6) give lowest decrement factor values (0.32) and burnt brick composite walls (C.W-2) give highest decrement time lags (9.1h) whereas cinder concrete composite walls (C.W-5) with coconut pitch insulation give highest decrement factor (0.42) and lowest decrement time lags (8.09h).

CONCLUSION

- Laterite stone and burnt brick composite walls with Coconut pitch insulation are the best composite walls for reduced cooling loads due to smaller decrement factors (0.30) and higher time lag values (9.1h) respectively, among studied composite walls.
- Mud phuska and coconut pitch have the least optimum fabric thickness (0.118m & 0.064m) among all the building and insulating materials studied respectively. Using these materials in construction, energy can be saved with smaller thicknesses of the walls.
- Mud phuska is the best homogeneous building material from the least decrement factor (0.5) and the highest time lag (6.74h) point of view among studied building materials and coconut pitch is the best homogeneous insulation material due to its lowest decrement factor (0.24) and highest time lag (11.41h) values among studied insulating materials. Hence, these are recommended for energy efficient building construction among studied materials.
- The insulating materials are fast responsive to short wave radiation than the building materials due to their higher surface factors and lower surface factor time lags. Hence insulation materials should not be exposed to direct radiation.

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Investigation on the Performance of Alternative Walling Materials in an Affordable Housing Unit situated in Warm Humid Climate

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ABSTRACT HEADING

The housing sector is the second largest energy consumer in India with 95 percent of urban population lying in the middle and lower income categories. Considering this demand for affordable housing, there is a strong potential for energy saving in the affordable housing sector. The given study delineates the gap in past research in creating comprehensive sustainable rating systems for energy efficient interventions in buildings and analyses the trade-offs in energy gains, economic cost and thermal comfort due to walling material substitution in warm-humid climate for an affordable housing unit. The study takes a government delivered affordable housing unit as case example. The DEROB-LTH software is used to simulate the hourly internal temperature throughout a day with six alternative walling systems. Hereafter, the three parameters – the embodied energy, cost of construction and the thermal comfort in terms of number of discomfort hours are compared to get a comprehensive sustainability assessment for the choice of walling materials. Flyash brick walls proved to be most efficient with respect to all three factors.

Keywords: Affordable Housing, Embodied Energy, Life Cycle Costing, Discomfort Hours, Thermal Simulations

INTRODUCTION

Being an emerging economy with rapidly rising per capita energy consumption and an increased dependency on energy imports, India is exposed to international energy market volatility and energy insecurity. As the urban housing sector of rapidly urbanizing India is facing a massive shortage of affordable housing, in order to address inclusive growth in the country, various affordable housing schemes are being planned by the Government of India in its five year plans. However all such policies and schemes [1][2], coming with hefty investments, fall silent upon energy consumption and conservation. The report of the high level task force on affordable housing chaired by Deepak Parekh in 2008 [3] defined the concept of affordable housing in terms of size of tenement, multiples of household

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income and in terms of percentage of household income for rented accommodation. In this report, an affordable house in Economically Weaker Section (EWS) or Low Income Group (LIG) category is defined as a unit with a carpet area between 300 and 600 sq feet, with the cost not exceeding four times the household gross annual income and EMI/rent not exceeding 40 percent of the household's gross monthly income. Evidently, such a nationally accepted benchmark also defined the capital cost components associated with affordable housing, but overlooked the factors related to sustainability and the associated recurring cost savings.

The building sector in India consumed 29 percent of the total primary energy demand in 2009 [4]. This energy consumption in affordable housing is small compared to high income residences, commercial and institutional buildings. However, the demand for affordable housing constitutes about 95 percent of the housing market in India [5] and hence forms a significant share of energy consumption in the household energy sector in the future.

Significant studies have been carried in Indian context by The Energy and Resources Institute of India (TERI) which promotes and defines the concept of green buildings through its own building rating system named GRIHA (Green Rating for Integrated Habitat Assessment) [6], adopted as the national rating system for green buildings by the Government of India since 2007. However the GRIHA guidelines give a sustainability scoring framework only and exclude the economic cost and comfort parameters that may be associated with energy efficient interventions for formulating a more holistic sustainable rating system achievable by the affordable housing sector. The Bureau of Energy Efficiency (BEE), which is a statutory body set up under the provision of Energy Conservation Act 2001, launched the Energy Conservation Building Code (ECBC) in 2007 [7] which sets minimum standards for energy efficient design, construction and retro-fitting. GRIHA has 34 criteria based upon which rating of a green building project is performed, of which the ECBC makes up three criteria (criteria 6, 13 and 14). But the primary target of the ECBC is limiting energy consumption of HVAC systems that consume about 30-45 percent of operational energy in mechanically ventilated buildings.

Considering this gap in the study of energy efficient interventions for affordable housing with naturally ventilated interior environment in hot countries, the given research explores a model for meeting a threefold target of improving life cycle energy consumption, minimizing cost and decreasing the perceived discomfort inside such housing units.

ENERGY CONSUMPTION FROM LIFE CYCLE ENERGY POINT OF VIEW

Life cycle assessment (LCA) is a technique which is defined by the International Standardization Organization as to measure the environmental aspects and impacts of product systems, from raw material acquisition to final disposal, in accordance with the stated goal and scope as in ISO 14040 [8]. For building industry, LCA measures the overall impact of a building and its components on the environment in three different phases – the construction or the pre-use phase, the operation or the post-occupancy phase and the demolition phase of the building in a cradle-to-grave analysis. Out of these three phases, the energy consumption in the third, i.e. the demolition phase is negligible compared to the first two phases. However relative energy consumption in the first two phases depends upon the functional type of building, choice of materials and the choice of ventilation for the interior environment. Past studies on comparing LCA for various types of residential buildings have shown that in case of a single family residential unit, the right choice of materials in the pre-use phase with a slight possible increase in embodied energy may lead to very high amount energy saving in the use-phase [9][10]. It has also been seen that there exists a linear relationship between the operational energy use and the total energy use in a building life span, but a similar relation is not applicable with the embodied energy of the building. Hence a solar house or a passive house proved to be more energy efficient from life cycle energy point of view compared to a house built with the commitment to use "green" materials [11]. Therefore, while choosing materials in the pre-use or the construction phase, the numerical value for embodied energy should not be the sole criterion for introducing green interventions in whole lifecycle perspective of the building.

Moreover, in Indian context, the concept of affordable housing is given by naturally ventilated buildings, since the cost of air conditioning adds considerably to the operation and maintenance cost, making it beyond affordability limits for the middle and lower income groups. As a result, the pre-use phase is an important target phase for energy efficient interventions for our aimed group of buildings, having an immense potential to provide an optimal thermal comfort during the building's use-phase.

The given study explores walling material interventions which form an important factor for heat gain inside naturally ventilated building in predominantly hot climates. The given methodology can be extended to study the performance of other building elements in a sustainability framework.

PROPOSED METHODOLOGY

Goal and scope of research

The objective of this study is to derive a model that will help to choose a particular walling intervention from a number of available options by assessing the performance in three different aspects – economic cost, thermal comfort and net energy saving in terms of embodied energy. Though the given study does not perform a whole building LCA, the methodology aims at assessing the performance of a building material in whole life cycle of the building, owing to involvement of comfort parameters which bears relation with energy usage in operating phase for combating thermal discomfort.

Functional unit - According to ISO 14040, the functional unit is the unit of comparison in the Life Cycle Inventory. In this study one square meter (m^2) of walling system is chosen as a unit and all energy consumptions and costs are expressed in terms of this functional unit e.g., MJ/m^2 and $Rupees/m^2$.

System boundaries - The system studies the embodied energy of the walling materials during the pre-use phase. The recurrent embodied energy for maintenance and replacement during the use-phase, which recurs yearly about 1 to 3 percent of the initial embodied energy depending upon the building lifespan [12], is excluded. Though wind speed is an important determinant for thermal comfort in warm humid climate, it is a comfort parameter regulated by the size and location of window openings. Hence the effect of convective wind speed on internal temperature has been excluded in this study.

Thermal perceptions and adaptive comfort equation

Comfort standards on thermal comfort are essentially based upon either heat balance or adaptive models. While the previous model is suited for conditioned environments, the latter is more appropriate for naturally ventilated buildings [13]. Toe and Kubota developed an adaptive thermal comfort equation for naturally ventilated buildings in hot-humid climates [14] using a statistical meta-analysis of the ASHRAE RP-884 database.

$$T_{neutop} = 13.8 + 0.57\, T_{outdm} \qquad (1)$$

Where T_{neutop} denotes neutral operative temperature and T_{outdm} denotes the daily mean outdoor temperature. This regression equation is applicable within a daily mean outdoor temperature range between 19.4 and 30.5 degree Celsius, with low (<0.3m/s) or moderate (<0.65m/s) wind speed at the neutral operative temperature, and with no required limit for relative humidity [16]. Equation (1) will be used to calculate the number of discomfort hours inside buildings in this study due to use of different walling materials.

Alternative walling systems

A walling system forms the vertical envelop of a building. The walling systems that have been compared in this study have been enlisted below:

- Ordinary brickwork 215 mm thick external and 115mm thick internal walls with 1:6 mortar bonds and 1:4 sand cement plaster

- Solid plain cement concrete (PCC) in-situ wall with 200 mm thick plastered external wall and 100 mm thick internal wall with 1:4 sand cement plaster
- 215 mm thick external and 115 mm thick internal fly ash brick walls with 1:6 mortar bonds and 1:4 sand cement plaster
- Brick cavity wall with 115mm thick external and internal brickwork with 1:6 mortar bonds and 1:4 sand cement plaster and an air gap of 30mm in between
- Autoclaved aerated concrete (AAC) brick walls 200mm thick with 1:6 mortar bonds and 1:4 sand cement plaster, both for external and internal walls
- Glass fibre reinforced gypsum (GFRG) rapid walling system [15], consisting of glass fibre reinforced gypsum board panels 124mm thick with hollow cavities in filled by reinforced cement concrete for structural strength both for external and internal walls. The walling system does not require plastering.

Case study building

The case study is a low income group housing complex located in the Rajarhat area, an eastern metropolitan extension of Kolkata. The region comes under sub-tropical warm humid climate zone owing to its latitude and proximity to the sea.

(a) (b)

Figure 1 - (a) Front side view and (b) back side view of building blocks

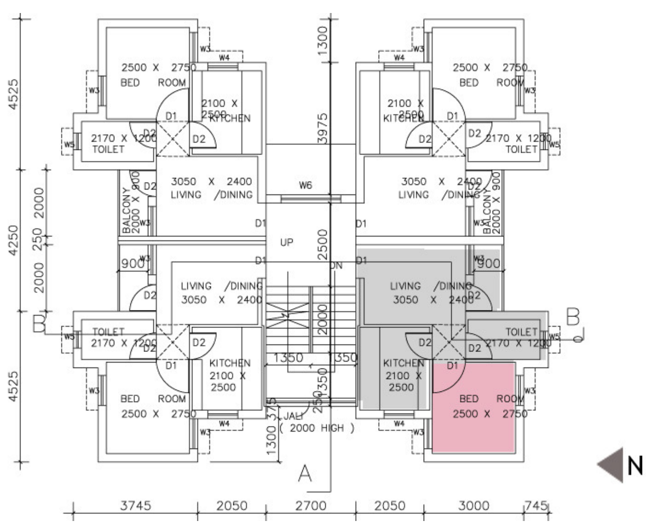

Figure 2 - Typical floor plan of a 'Starlit' housing block highlighting the bedroom in the south-west oriented unit, simulated for hourly internal temperature

The case study buildings, **as shown in figure 1,** were built in an affordable housing scheme named 'Starlit Housing' and delivered by the State Housing Board in 2011. The buildings have been occupied since then by low income group of residents. Each block is a four storied building and the entrance of each is oriented in the east-west direction in the site plan. Each floor has one-bedroom units, four in number, oriented in the four different intercardinal directions. The study took a south-west oriented unit as case example for carrying out simulations, **as shown in figure 2**.

Simulations

For simulating the internal room temperatures in the case study unit, the study used the DEROB-LTH software originating from the University of Texas at Austin, USA and further developed by the Department of Energy and Building Design at the Lund University, Sweden. The software uses the Crank-Nicholson's Difference method for heating diffusion equations in walls and the Gauss-Seidel method is simultaneously used to solve the temperature difference in nodes. Nodes are assigned to walls and windows for energy transmission [16]. The hourly internal temperature simulation has been validated in several past studies [16] [17].

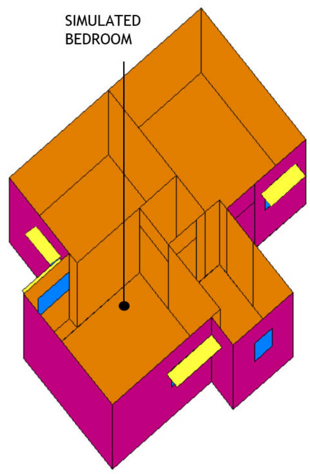

Figure 3 - DEROB model showing the bedroom whose internal temperature has been simulated with alternative building materials

Choice of orientation - The south-west corner was chosen for simulation. The chosen orientation is due to the sun path from east to west via south in the northern hemisphere, and the west facing rooms having maximum discomfort during the daytime due to excess glare from sunlight.

Choice of date - The chosen day for hourly indoor temperature simulation is March 20th of a typical year from the Meteonorm climate database fed in the DEROB-LTH software. This is the spring equinox day in the northern hemisphere with equal days and equal nights which indicates the onset of summer.

Parametric modelling – The DEROB program can handle upto eight volumes and upto hundred walls. Due to these modelling limitations, only one of the units has been modelled and the internal temperature in the south-west facing bedroom has been simulated as shown in the **Figure 3.**

The parametric simulations have been run in a closed window scenario assuming 30 percent absorptivity for the walls and the roof, which is the highest absorptivity for white painted surface [18]. Simulations have been carried out for a ground floor unit using the standard RCC roof, single glazed windows and plywood doors.

Material database – The material databases for simulation have been derived from [19] for flyash, [20] for autoclaved aerated concrete, [15] for GFRG rapid wall and the rest from the DEROB-LTH database.

RESULTS

The embodied energies of the alternative building materials were calculated from [21] [22] [23]. The cost of construction are as per West Bengal Public Works Department schedule rates for 2010 [24] till its fourth amendment. The rates for GFRG panels and AAC blocks have been derived from [17] and [25]. The costs compared below include the cost of plastering but exclude the cost of painting.

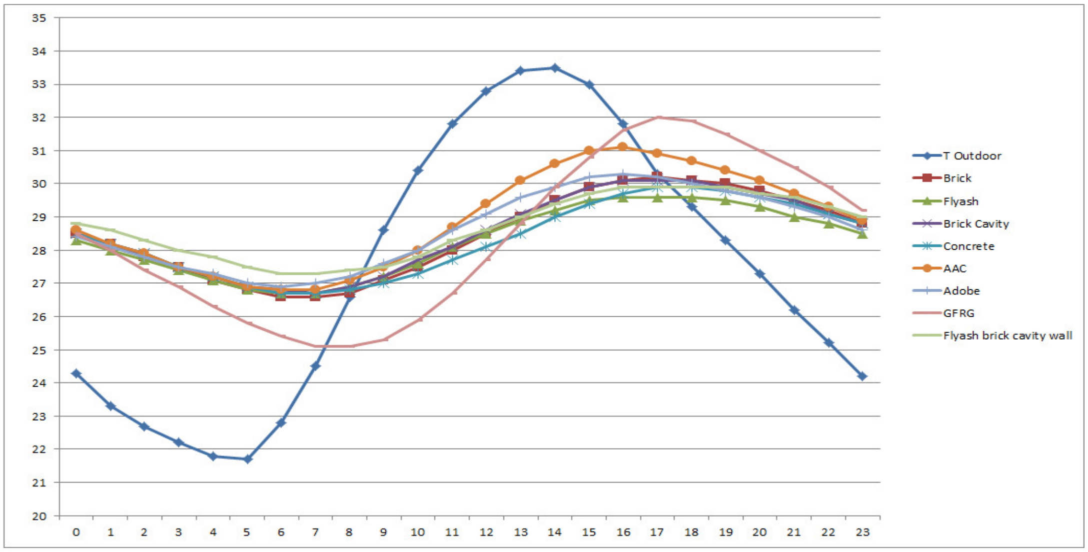

Figure 4- Simulated room temperature in various wall types with alternative building materials

The **figure 4** shows the internal simulated temperatures (T_s) for all the walling systems used in this study, done in the DEROB-LTH software. The number of discomfort hours is obtained by comparing the value of T_s for each hour with the neutral operative temperature (T_{neutop}) on the given date (March 20) of a typical year, which was 29.38 degC against a daily mean outdoor temperature (T_{outdm}) of 27.3 degC. The degrees of discomfort were calculated by taking the cumulative of the excess temperatures above the T_{neutop} during the discomfort hours.The graphs clearly delineate the time lag in heat content of the building materials, having higher internal temperatures in the later parts of the day. The **Table 1** gives a comparative analysis of the walling elements in cost, comfort and energy saving scale. Brick cavity wall seems to give marginally better thermal comfort than ordinary brick wall. Thermal discomfort seems to be highest in aerated concrete walls. Flyash bricks are found to be most efficient in terms of all three factors.

Table1. Material properties in terms of cost, comfort and energy saving

Walling system	Embodied Energy (MJ/sq m construction)	Construction Cost (Rs/ sq m construction)	No. of Discomfort Hrs (T_{neutop}=29.38^{0}C)	Degrees of Discomfort (T_{neutop}=29.38^{0}C)
Ordinary Brick wall	1231.0	1451.46	8	4.06
Brick cavity wall	1118.5	1462.39	7	2.84
Solid PCC in-situ wall	441.36	1675.60	7	2.04
Fly ash brick wall	376.5	1272.34	5	0.9
AAC wall	369.0	1028.00	10	10.2
GFRG rapid wall	474.0	1620.00	9	14.7

DISCUSSIONS

The given study is carried out in warm humid climate characterized by uncomfortable summers where it is important to simulate the peak summer temperatures for thermal comfort. However the average outdoor temperature for 21st June, which marks the summer solstice or the peak of summer, did not fall in the temperature range for which the adaptive thermal comfort equation, used in this study, is applicable. Hence this date could not be taken for the study. Instead the spring equinox day occurring on 20th March was assumed for demonstrating the thermal comfort performance of the building walling materials in terms of number of discomfort hours. This particular shortcoming was addressed by introducing two indicators of thermal discomfort – "number of discomfort hours" and cumulative of the degrees above the neutral operative temperature on the particular day given by "degrees of discomfort". Flyash bricks were seen to excel in both the thermal performance indicators. The simulated temperatures for June 21st gave discomfort hours round the clock for almost all the materials, the T_{neutop} in such case being assumed from the upper limit of the T_{outdm} for the equation (1), which is 30.5 degC. Hence these results were not shown in the study. However the comparative ranking of various walling materials on rhermal comfort on this day based upon the "degrees of discomfort" indicator followed a trend similar to 20th March.

The comparative performance assessment for thermal comfort for various walling materials in the given study is also dependent upon the specific heat, density and thermal conductivity of the walling materials. These three physical properties are often seen to vary with the manufacture of the material and the proportion of its composites. The thermal properties of AAC blocks for example are largely dependent upon the proportion of flyash in a block. Hence these results are subject to variations depending upon changing material compositions and properties. Thus the target of the given study is to delineate a methodology for sustainability assessment of various walling materials based upon the available data inputs.

CONCLUSION

This paper is a part of an ongoing doctoral research on energy efficient interventions for affordable mass housing. The results obtained from a larger study, which will simulate the thermal discomfort of various combination of building materials in all summer months, will be assessed in a multi objective optimization framework in a later stage.

Though the study is being carried out for low income group housing units, the results are universally applicable for all housing units with naturally ventilated interiors in warm humid climatic conditions like Kolkata. Past studies in the Indian context [26] and abroad [27] have considered optimizing the economic cost and energy saving, however did not take the internal thermal comfort as an objective for consideration. Hence this paper indicates a new approach for developing a comprehensive performance rating for alternative building walling materials.

ACKNOWLEDGMENTS

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NOMENCLATURE

T_s = internal simulated temperature

T_{neutop} = neutral operative temperature

T_{outdm} = daily mean outdoor temperature

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Parametric design for technological and "smart" system. Adaptive and optimized skin

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ABSTRACT

The goal of this research is to develop technological and "smart" complex building skin systems, particularly façades, through the development of "emerging technologies"[1] and of a reputable multi-disciplinary approach. The awareness that innovation in architecture, but also generally in science, is essential to provide concrete answers to issues of general interest, such as energy resources consumption and the obsolescence of construction systems that have been used so far, makes research fundamental and priority. It is necessary that architecture becomes adjustable to the environment ,like living organisms, through a new multi-disciplinary approach: studying not only the morphology but investigating also the generative process starting from the physical characteristics of materials and components as well as analyzing bio-inspired systems, resulting in an architecture that is increasingly adopting the form of a living organism. In order to achieve this, efficient technologies and mutually collaborating systems are required that can only be achieved through research in the field of emerging technologies. Specifically the approach presented in this paper provides the basis for the development and prototyping of a "light" dynamic and adaptive façade system that is able to synthesize the different contributions that these new technologies are able to provide. In the second step of the research thus a new methodology and a new design process had to be defined (involving major innovations in the design and prototyping of technological systems to be transferred to the industrial sector), with the intent to ensure the necessary product innovation to compete at a global level and to establish a standardized and repeatable design process also for other smart façade systems.

The knowledge of the "state of the art" and critical, directs research towards a prototype system of flexible façade based on pre molded components and achievements obtained by the nonstandard and avant-garde processes, even experimental, which contains sub-systems able to collect input from outside and rework them to provide an adaptive and optimized response.

Keywords: Parametric modeling; computational design; adaptive; optimized; high performance skin system.

INTRODUCTION

[1] The term "emergent technologies" - defined by M. Hensel, A. Menges and M. Weinstook in the book "Emergent technologies and design. Towards a biological paradigm for architecture" (2010) - indicates a new science that - on the basis of the study and the understanding of the mathematical complexity of natural systems - aims to transfer such complexity within technological systems to achieve optimized and adaptive performance

Given the importance it plays worldwide, nowadays, the innovation and the research for new strategies and new technological systems in construction industry is a necessity. Construction industry is one of the biggest sectors of industry in the world in terms of employment, earnings, influence and energy resources use. Indeed, in EU countries this sector "consumes" 30-40% of the energy resources and 50% of the global resources only during the construction process. Similarly it is possible to say that the construction industry and the technologies and components used in manufacturing processes, are still linked to the use of standard materials that dominate the market - such as reinforced concrete, steel and glass - and obsolete constructive and productive systems. The industrial revolution of the 19^{th}-20^{th} century, based on the serial process, produced very efficient but very expensive systems in terms of energy demand and need for raw materials. Today this process has definitely to be rethought involving experiments on new materials and new production and realization technologies such as robotics, additive processes, morphing and especially 3D surface printing.

Figure 1 Robotic fabrication printing «ICD/ITECH research pavilion 2012»

One of the elements that affect more buildings, in terms of cost of construction and maintenance, energy demand, thermo-hydrometrical and acoustic comfort, is the “building skin” understood as a complex element capable of modifying inputs from the surrounding environment . Technology evolution, particularly in expansion in recent years, has transformed the “building skin” from passive to active, resulting finally, in a hybrid skin, in which building and plant technologies become complementary to each other and the building skin becomes part of an integrated building-plants, equipped with devices of regulation and control that placed it at the center of experimental processes in prototype models of futuristic living field.

Figure 2 Material deposition 3d printing «D-shape 3d printing»

If research on the topic of “building skin” has reached a level of development on the energy and environmental side, on the other side today we need to introduce new variables in this process affecting the generative process in architecture. The adaptive aspect of architecture related to the variable conditions of the surrounding world such as social needs, climatic conditions and human iterations, forms the basis for future testing: analyzing how everything variable and dynamic can affect architecture and its technological components. Besides the three, now consolidated, macro-categories which characterize passive, active and hybrid façades we have to introduce a fourth category being *“intelligent and dynamic”* façades.

Figure 3 Adaptive and optimized surface «ICD/ITECH, Hygroscope meteosensitive pavilion, 2012»

METHODS AND EXPERIMENTATION

This new approach to intelligent technological systems, in particular regarding façades, needs a different methodological approach and needs to introduce new systems of experimentation able to reduce the current gap between practice and research.

This research consists of two experimentation works focusing on intelligent façades for innovative building prototypes. The chosen typology is "tower buildings", characterized by almost zero energy consumption, high adaptability and high energy efficiency and locate in the Mediterranean area. The new bottom-up approach allows to optimize the processes of analysis and to obtain optimized results. The interaction between architecture and environment, leads inevitably to analyzing natural systems. The analysis of the system in relation to the external inputs is the basis of the creation of the genotype (generative algorithm) and of the analysis of the phenotype (physical model). Both experimentation works are localized in the area of Ascoli Piceno, Italy lat. 42° 51' - long. 13 ° 35 '. The climate files were carried out by Meteonorm and Ecotect software.

The first experimentation work aims at optimizing the energy performance of the building skin in tower buildings in order to identify , their "energetically active parts", through the definition of a range of values and to determine their annual gain in terms of energy production. Specifically, after defining the reference weather conditions and the object geometry, the environmental analysis was conducted using a software able to optimize the skin behavior. Thanks to parametric design tools in Rhinoceros software - in particular the link between Grasshopper and its plug-ins Geco and Ecotect - it was possible to evaluate in real time the effects of any changes made in the designed building skin.

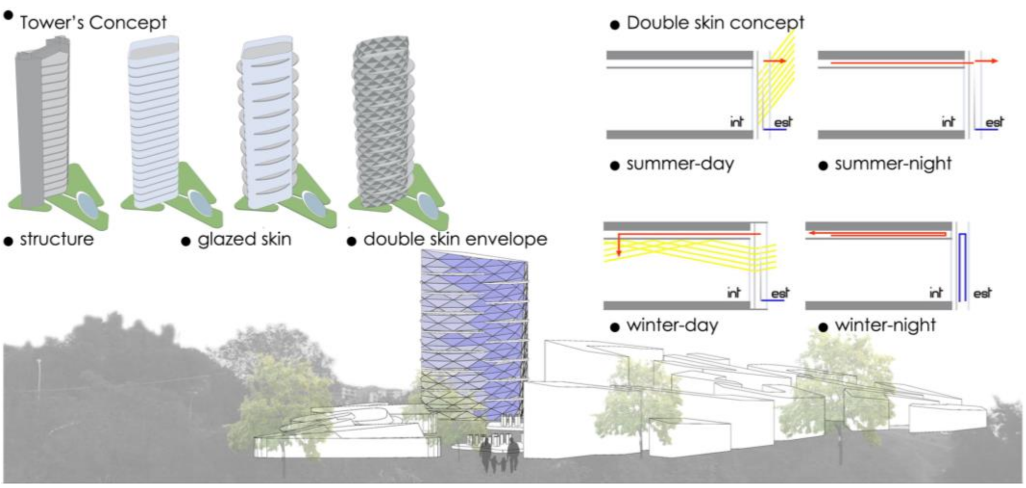


Figure 4 Tower's design concept: double skin development and conceptual design of the tower building in an urban context.

It was decided to use a dynamic double skin façade. As a first step, the geometric pattern of the outer skin was defined through its panelling with the plug-in Launchbox[2] in Grasshopper environment. In the second step the skin was analyzed from an environmental point of view with the software Ecotect. Among the analyzed parameters, special importance was given to the solar irradiation on the outer surface, expressed in kWh/year. In this way it was possible to define the “energetically active” part of the outer surface and to obtain an early pre- dimensioning of the façade system and an estimate of its energy production.
In addition, the methodology of this experimentation and work can be repeated for different climatic zones and for different architectural configurations by replacing the weather file in input stage.

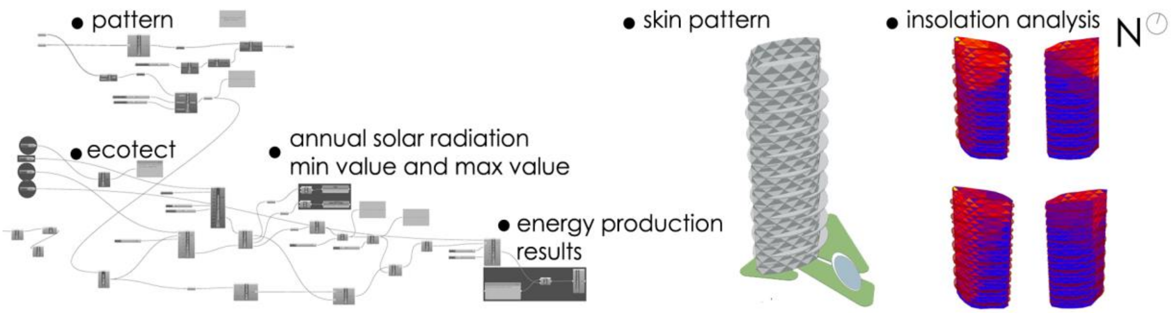


Figure 5 Bottom-up process for skin optimization: process for the evaluation of incident annual solar radiation through the link between Grasshopper and Ecotect.

The second experimentation work aims at defining an intelligent and adaptive technological system to be applied to tower buildings, able to ensure an optimized response to inputs coming from the external environment. Specifically, after identifying the adaptive system, the analyzed surface “was panelled” using the software package Grasshopper inside Rhinoceros, and then the result were evaluated using the software Ecotect and Geco. Once input process, climate files and geometry were defined, the surface behavior was analyzed in response to the inclination of the solar irradiation, in order to study its dynamic and adaptive potentiality.

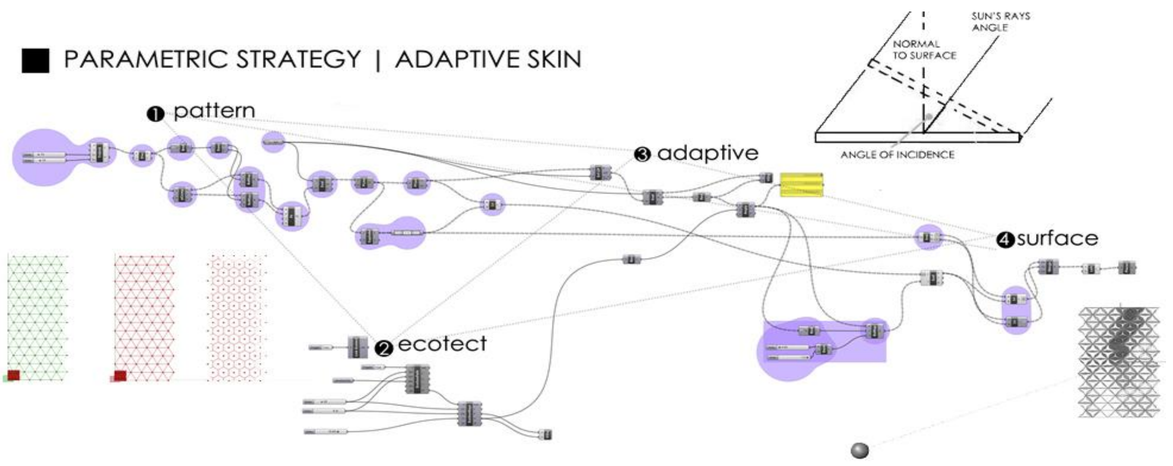


Figure 6 “Panellization to adaptation” process: adaptation of daylight system in Mediterranean area.

In particular the image shows the adaptation of the skin surface in relation to the inclination of the suns’ s rays and the process:
The dynamic analysis of an adaptive device is preparatory to the creation of the technology scheme of the

[2] Launchbox is a free plug-in for Rhino-Grasshopper, for the surfaces panelization. With this plug-in it is possible to define a geometrical pattern and to analyze it in all its parts (nodes, rods, panels).

façade. In the first phase of this second experimentation work the components of the façade are identified and classified into two types:

- Fixed parts: primary structure composed of panels of varying sizes (maximum extension 1.95 x 1.75 m) realized with innovative production systems, robotics and CNC fabrication,
- Moving parts: extensible cables to ensure the correct dynamic operation of the panels made from innovative materials including bioplastic and fibro elastic textiles.

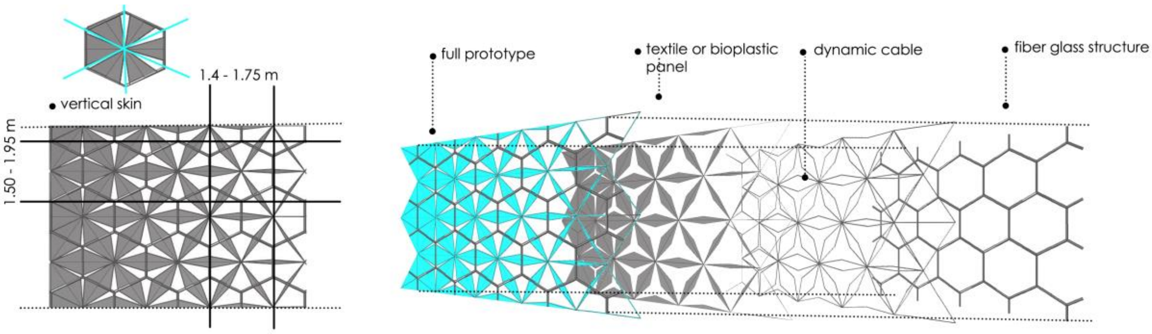


Figure 7 Skin design: a possible development of the skin system for the environmental rehabilitation of buildings in the Mediterranean area.

EXPERIMENTATIONS AND RESULTS

Both experimentation works aim at studying the behavior of surfaces in response to specific environmental and climate input changes; in the first case the incident solar radiation on the entire surface, measured in kWh/year, is used to define the energetically active parts of the surface and assess the need of technological devices able to shield and avoid its overheating. In the preliminary project phase, better don't underestimate the possibility to assess the energy gain derived from the surfaces energetically active parts.

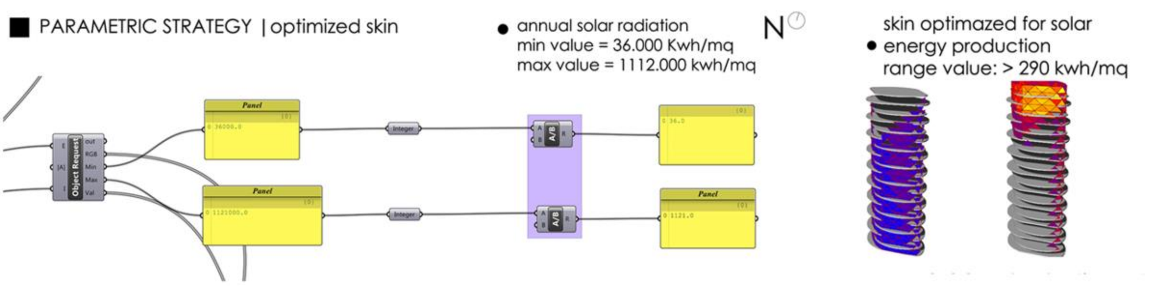
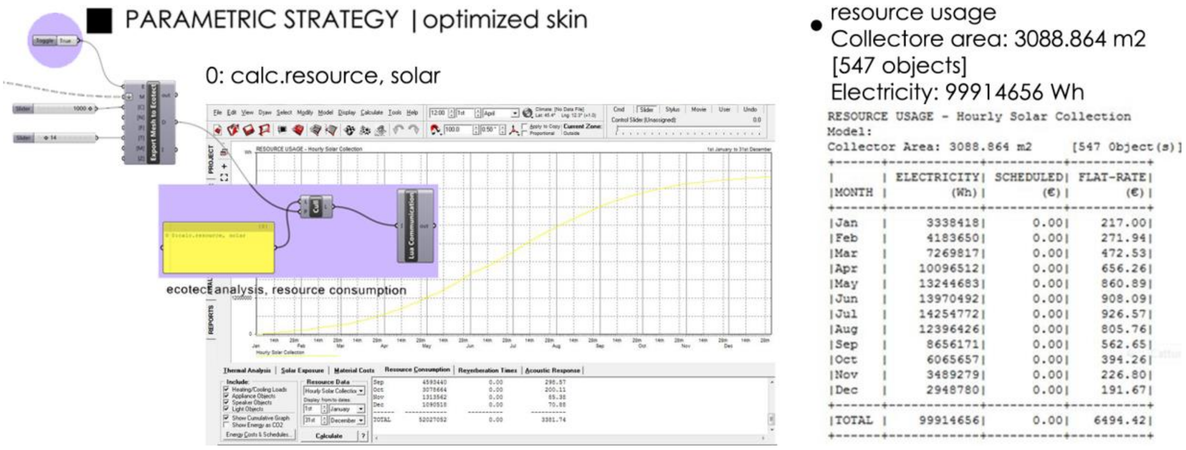


Figure 8 energetically active parts of the buildings surface and assessment of the need of technological devices able to shield and avoid its overheating through the definition of a range of values.

In order to define the energetically active part of the skin and in accordance with the climatic characteristics of the project site and with the chosen HVAC system a range of annual energy demand between, < 290 and >290 kWh / year was established. Thanks to the use of the LUA script COMMAND - present in Geco - it was possible to estimate the production of electricity, expressed in kWh/ year. The script "0: Calc.resource, solar" allows to calculate these gains through the link with Ecotect, panel analysis and resource consumption, and to estimate the area of application and the number of used elements. The direct connection between skin geometry, geometric pattern and analysis software environment, allows also to have a real-time update of the analysis with respect to geometric variations typical of the early stage of architectural and components design.



MONTH	ELECTRICITY (Wh)	SCHEDULED (€)	FLAT-RATE (€)
Jan	3338418	0.00	217.00
Feb	4183650	0.00	271.94
Mar	7269817	0.00	472.53
Apr	10096512	0.00	656.26
May	13244683	0.00	860.89
Jun	13970492	0.00	908.09
Jul	14254772	0.00	926.57
Aug	12396426	0.00	805.76
Sep	8656171	0.00	562.65
Oct	6065657	0.00	394.26
Nov	3489279	0.00	226.80
Dec	2948780	0.00	191.67
TOTAL	99914656	0.00	6494.42

Figure 9 Thanks to Geco and Lua Command Script we can underestimate the possibility to assess the gain derived from the surfaces energetically active parts.

In the second experimentation work the adaptive capacity of the buildings external surface was tested in relation to the solar path, angle and incidence on the surface. The process aims particularly at defining a dynamic surface able to open and close in an adaptive way according to the variation during the time of the external conditions inputs, in particular of natural lighting. The optimization as a guide in complex processes. Main difficulties, until a few years ago, resided in the technological know-how that would allow to consider architecture as a living and adaptive organism. Each architecture would have its genetic composition and a specific combination of genes. The genotype will represent the intrinsic characters while the phenotype would be the character set that the architecture shows clearly. In biology it's well known: the phenotype depends on the genotype but also by iterations between genes and environment.

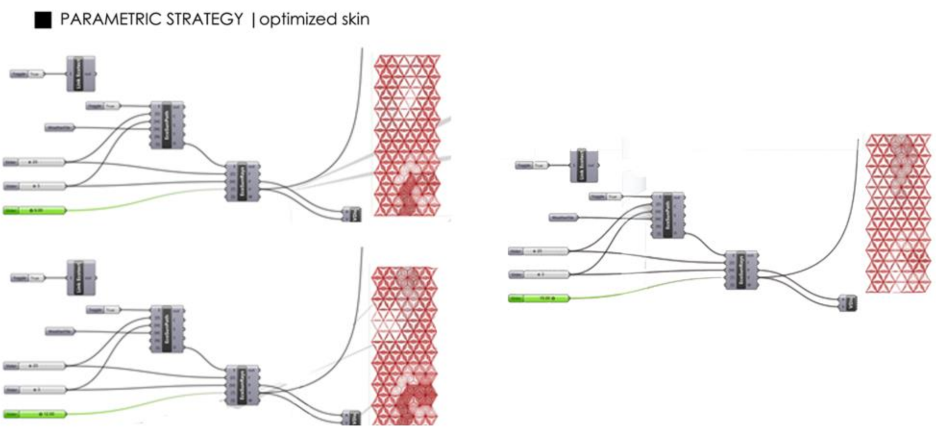


Figure 10 Adaptive capacity of the building external surface is tested in relation to the solar path, angle and incidence on the surface three times of the day.

The ability to analyze the dynamic behavior of building skin technological components is fundamental in the preliminary phase of the design as it allows to significantly reduce the gap between digital design and physical experimentation.
Considering the large amount of available data, commonly called “open data”, it is not difficult to imagine how such a process can bring substantial advantage, especially in building retrofitting, where is necessary to add new parts or components in order to reduce the energy demand and ensure a adequate indoor comfort level compatible wit the actual standards and regulation.

APPLICATION IN EXISTING BUILDINGS

In Italy, the country chosen as a case study for this research, in fact, there is no need to build many new buildings, while a big problem consists of existing buildings, mostly made in the years 60'-80 'and characterized by a high energy consumption and a low level of environmental comfort inside. Therefore, it is necessary to find a solution to this problem, mainly caused by building envelopes of poor quality and obsolete buildings in general. A dynamic and adaptive technology device (e.g. a building skin designed to respond to specific input from the external environment), can formally design in an innovative way the existing façades and also reduce the problems arising from excessive solar radiation, e.g. overheating of the exterior walls and of the interior spaces.

The developed adaptive envelope system has been applied in existing tower buildings, located in Ascoli Pieno and realized in the 80's. This application is actually in a test-phase, but the experiments made so far are giving very good results.

Figure 11 The image show the possible application of dynamic façade in Ascoli Piceno area, Italy lat. 42° 51' - long. 13 ° 35 ' .

CONCLUSION AND OUTLOOK

The presented research proposed a new bottom-up process for developing a new type of building's dynamic façade. Skin becomes a technological intelligent system that interfaces with the external environment and its inputs. In this way the technological system is equipped with artificial intelligence able to collect and process data from the environment in order to return an optimized and adaptive response. If at the dawn of the modern movement response the slogan was "form follows function" today, thanks to the developed digital technology, it is possible to safely talk about "form follows energy flows". The use of parametric modeling software combined with assessment tools and simulation of environmental performance, allows the development of technology components which record and respond to climate change creating a further project phase. In addition the skill of ensuring the kinetic movement, through the use of nanotechnology and smart materials and the possibility of strongly reducing the manufacturing imperfections through the digital manufacturing, can further reduce the gap present between digital and physical experimentation and production and ensure a better relationship between construction costs and performance of device.

In the next step of research the main objective is a territory research of companies able to invest and ensure technical and financial support for the realization of the prototype. The final goal is to create a database, clear and easy to read, able to make the know-how available immediately and to reduce the gap between the research subject and the industrial production world.

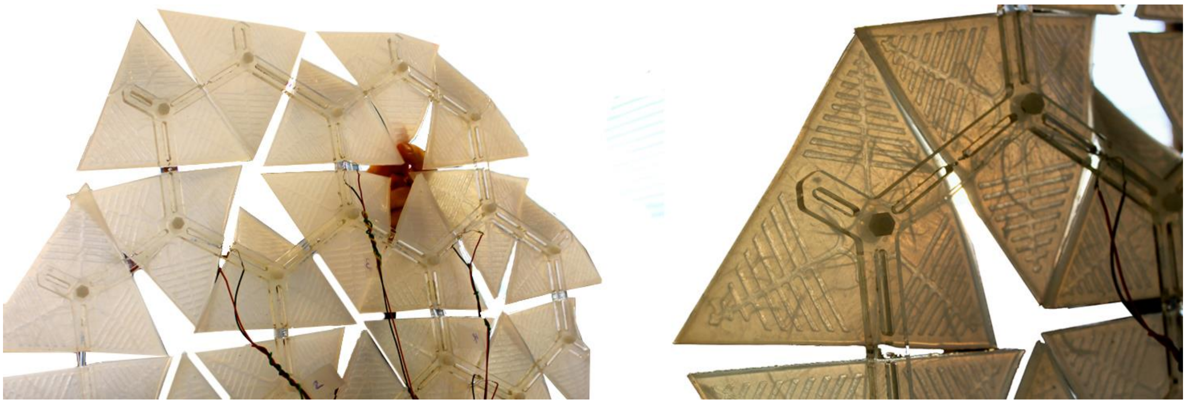


Figure 12 Model prototype of dynamic skin for physical analysis with Arduino board «Eth Zurig, Adaptive System Lab».

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The Influence of Insulation Styles on the Air Conditioning Load of Japanese Multi-Family Residences

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ABSTR ACT HEADING

The performance of building envelopes significantly affects the indoor energy consumption, thermal comfort, and durability of a building. Numerous studies have focused on the thickness of insulation materials and considerations for insulation placement (installing insulation inside or outside the wall), however most of the studies have discussed insulation placement in each building's components and form (wall, roof, floor), and very few of them have considered the insulation as an insulation system of the building. In 1999, the Japanese Institute for Building Environment and Energy Conservation issued the standards for residential energy efficiency that specified the standards of building envelope thermal transmittance and overall heat loss coefficients however; the insulation placement was not well explained. Additionally, it is common in Japan to use intermittent air-condition systems rather than having the air conditioning units continuously operating. It is necessary to investigate the performance of insulation taking into consideration the specific life styles of people living and working in Japan. In this research, we will (1) develop new interior insulation to conduct insulation on all of the interior surfaces of building units (walls, ceilings and floors) for environmental building design based on the calculation of heat loss; (2) discuss and demonstrate the effect of high heat capacity on each of the building components and thermal bridge by building environmental simulations; (3) carry out the simulation in different cities in Japan (Sapporo, Hachinohe, Sendai, Toyama, Tokyo, Miyazaki and Naha) and discuss the applicability in these different areas of Japan. Comparing the environmental qualities among three insulation styles (outside insulation on outside walls, inside insulation on outside walls, and interior insulation which is an innovative insulation style in Japan), the energy saving and thermal comfort advantages will be demonstrated. This research will provide an innovative insulation style that could contribute to new generations of energy-saving standards and formulations in Japan.

INTRODUCTION

In order to tackle global environmental issues in Japan, the "Act of The Rational Use of Energy" and the "Energy-Saving Standards for Houses and Buildings" were reformed in May 2008 and January 2009 respectively (IBEEC, 2009). These were aimed not to improve energy conservation performance at individual houses, but rather to focus on promoting and spreading energy savings throughout the whole housing industry, indicating that further discussion of housing energy savings will be anticipated. Therefore, we once again need to clarify the features of different insulations in common housing complexes, as well as how insulation affects indoor thermal environment and energetic load (Wang et al., 2010). Meanwhile, the building envelope thermal performance consideration shows building materials with high thermal insulation properties should be used in the outer walls, floors and other parts

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of the building envelop (Evans et al., 2009). This guideline is not including a detailed indication about the difference of outside and inside insulation with a dynamic indoor and outdoor enviormant and the comparsion of the impacts of Heat Bridges. We need to coordinate indoor thermal environment that are looked around about thermal comfort as shown by (Kuma et al., 2008). This study aimed indoor thermal environment and comfort. Three insulation methods were compared from an indoor thermal environment perspective in which the room temperature, surface temperature, operative temperature at a model dwelling unit was adjusted by Thermal Load Calculation Software (THERB) to modify conditions such as location, climate and air conditioning. This research could contribute to the expansion of Japanese sustainable building standard development.

METHODOLOGY

Environmental Simulation Program

For the environmental performance evaluation, simulation program "THERB" was used in this research. THERB for this analysis is dynamic simulation software which can estimate temperature, humidity, sensible temperature, and heating/cooling loads for multiple-zone buildings (Ozaki, 2004; Ozaki and Tsujimaru, 2006). THERB has the following features:

1) Successive transition method and a trapezoid hold function that can adjust itself to a time-discrete domain are used.

2) Dimensionless equations are used to calculate convective heat transfer coefficients for every part of the unit under study.

3) Longwave and shortwave absorption coefficients are taken into account in order to simulate the net absorption of radiant heat and transmitted solar radiation.

4) A multilayer window model, which defines the overall transmittance, absorptance, and reflectance of solar radiation, is used. (At present, the model cannot account for window curtains.)

5) A network airflow model is used to calculate ventilation quantities.

Model

The unit model that used in this simulation is a common dwelling in a residential complex in Tokyo; that mentioned in Journal of Architectural Knowledge (2004). We are going to analysis the unit which is on the middle floor, at the centre of the floor. Figure 1 shows floor plan, and figure 2 shows the details of three insulation types.

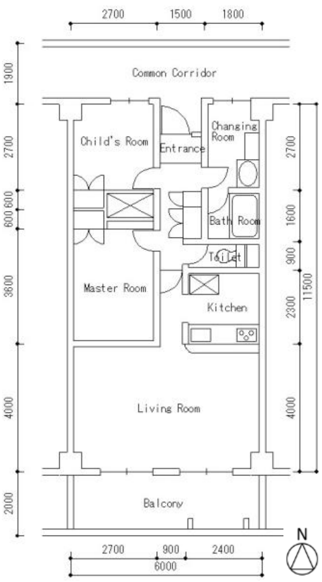


Figure 1. Unit Plan

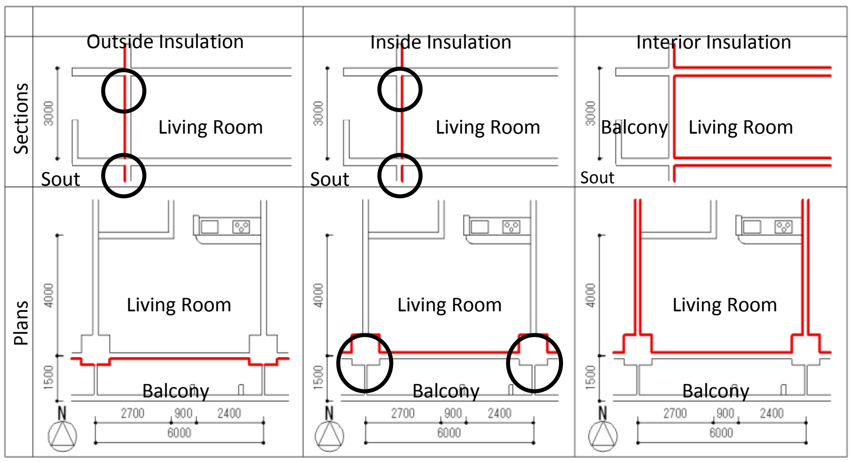


Figure 2. Details of the Three Heat-Insulation Styles, Dark Circles are Showing the Locations of Heat Bridge

Heat Insulation Styles

In the 1980s, interior insulation used to be the common insulation style in Japan. However, dewing inside of the wall was observed in most of inside insulation buildings, because of the underdeveloped construction technique at that age. After that, outside insulation is becoming the common insulation style in Japan, but the performance on thermal comfort and energy consumption between these two insulation styles are still being argued in the academic world. A new insulation style as the promoted inside insulation is proposed and compared with the traditional outside insulation and inside insulation.

In the interior insulation method, not only areas exposed to the air such as external wall and roof but also confining wall, flooring and ceiling were insulated aiming to insulate the whole building from the inner side. We complied with the Next Generation Energy-Saving Standards regarding what materials were used, how thick they were or where they were installed. Three kinds of Class A Extruded Polystyrene Form Heat Insulation were mainly used as insulation materials. High Grade Glass Wool 16K was used on the flooring only for the interior insulation4). Except for the external wall and roof for the interior insulation, the thicknesses of insulation materials were 30mm Class A Extruded Polystyrene Form Heat Insulation for walls and 50mm High Grade Glass Wool 16K insulation for flooring. Figure 2 and Table 2 show location and thickness of insulation materials.

HEAT LOSS CALCULATION

Currently, in Japan, standards and guidelines such like CASBEE and “Explanation of the energy-saving standards for houses” are indicated the performance about inside insulation and outside insulation of exterior walls and floors. However, these discussions are not including the consideration about interior walls and ceiling, which also has a high heat capacity to affect the indoor thermal comfort and energy use. Meanwhile, heat loss through Heat Bridge is also a big issue of building thermal performance. In this section, thermal resistance and thermal transmittance are calculated following equation 1 and 2, and the results are showing in table 1. The total heat loss by thermal transmittance of the unit model is calculated according to equation 3 and the unit construction and volum, and the result is shown in figure 3.

Thermal Resistance ($m^2 \cdot K/W$) = Thickness (m) / Thermal Conductivity ($W/m \cdot K$) **(1)**

Thermal Transmittance (U) ($W/m^2 \cdot K$) = 1 / Thermal Resistance ($m^2 \cdot K/W$) **(2)**

Heat Loss through Thermal Transmittance (W/K) = $U \cdot A \cdot K$ **(3)**

Where: U is Thermal Transmittance ($W/m^2 \cdot K$)
A is Area (m^2)
K is Temperature Difference Coefficient (K=1.0, for exterior walls)

Table 1. Thermal Transmittance Calculation

Exterior Walls

	Thickness (m)	Thermal conductivity (W/m·K)	Thermal resistance ($m^2 \cdot K/W$)
Extruded poly styrene foam blooks A-3	0.03	0.028	1.07
Concrete	0.20	1.600	0.13
Plaster board	0.01	0.220	0.05

Total thermal resistance ($m^2 \cdot K/W$)	1.24
Thermal transmittance ($W/m^2 \cdot K$)	**0.81**

Heat Bridge

	Thickness (m)	Thermal conductivity (W/m·K)	Thermal resistance ($m^2 \cdot K/W$)
Concrete	0.20	1.600	0.13
Plaster board	0.01	0.220	0.05

Total thermal resistance ($m^2 \cdot K/W$)	0.17
Thermal transmittance ($W/m^2 \cdot K$)	**5.87**

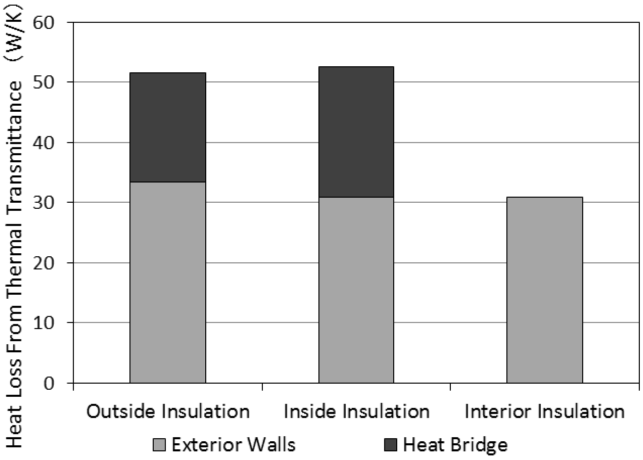


Figure 3. Heat Loss by Thermal Transmittance with Three Insulation Styles

As the result in the table 1, the thermal transmittance of Heat Bridge is over 7 times of that of exterior walls. Heat loss through Heat Bridge is obveriously higher than that through exterior walls. According to that pointed in figure 2, Heat Bridge in the units with exsting outside insulation and inside insulation style could be founded between the floor and the exterior walls, and between the pillers and interior walls. In the porposed interior insulation unit, Heat Bridge could be avoided by conducting insultion at all of the interior surfaces. Compare the total heat loss through unit envelop among three insulation types, the unit with inside insulation is slightly higher than outside insulation unit. This is because of the Heat Brigh between the pillers and the interior walls which is not exst in outside insulation units. The heat loss in units with interior insulation is about 40% lower than the other two units. This is because of the promotion in the respect of Heat Bridge. Heat loss through the exterior walls is also slightly changed by the different insulation thickness requirement by “Explanation of the energy-saving standards for houses” in Japan, which is indicated in table 2. But the consideration of the whole unit and the comprehensive building envelop thermal performance, the consideration of the complete combination of the insulation performance in each building components is also an important issue for building thermal insulation.

AC ENERGY CONSUMPTION IN VARIED JAPANESE CITIES

Simulation Details

In this simulation, we used reference data from Expanded AMeDAS Weather Data that in the period between 1981 and 2000. We compared the effects with different weather conditions. We chose seven target cities in six areas that assigned in Japanese Next Generation Energy-Saving Standards (Explanation of the energy-saving standards for houses) by different weather characters. Figure 4 shows the location of seven cities. The average temperature in north cities is lower than that in south cities.

According to different areas, the recommended thicknesses of insulation materials are provided in the Explanation of the energy-saving standards for houses in Japan. The detail of varied insulation materials thickness is showing in table 2. Considering the different characters of seven cities, heating and cooling periods are varied. Heating period is that monthly average temperature is equal to or lower than 15 ℃ (setting temperature: 20 ℃, percentage humidity: 40%). Period of cooling is that which monthly average temperature is higher than 15 ℃ (setting temperature: 26 ℃, percentage humidity: 60%). Table 3 shows varied heating and cooling period in different cities.

To observe how difference in life style affects heat load, we prepared four different air-conditioned rooms where residents with a different lifestyle were allocated to live with different AC usage patterns. Table 4 shows the AC details. These conditions were as follows:

①. No one is at home during the day, and the air-conditioner is not in use during sleeping hours. (A couple with dual income no kids – DINK);

②. No one is at home during the day, and the air-conditioner is not in use during sleeping hours. (A family consisting of a husband, a full-time housewife and a primary school child.);

③. No one is at home during the day, and the air-conditioner is in use during sleeping hours. (An elderly couple);

④. 24-hour air-conditioning.

Additionally, all rooms were continuously ventilated once every two hours, as well as automatically ventilated on an as-needed basis in the living room, dining room, kitchen and bathroom.

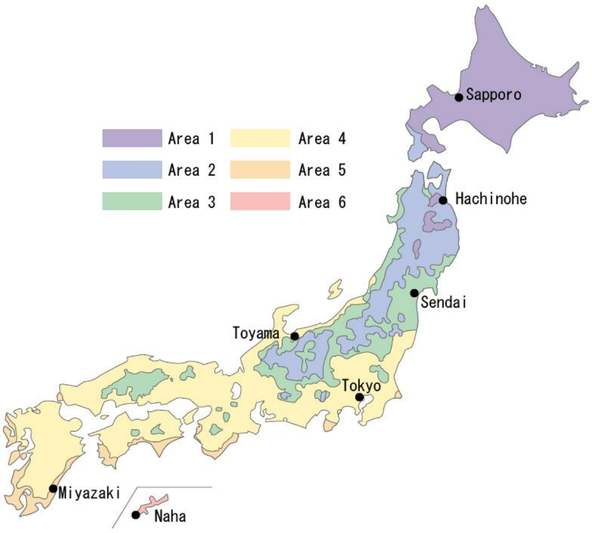


Figure 4. Weather Areas and Target Cities

Table 2. Thickness of Insulation Materials

Area	Thickness (mm)	Outside	Inside	Interior
1	Ceiling	85	105	105
	Exterior Wall	55	65	65
2	Ceiling	65	80	80
	Exterior Wall	45	55	55
3, 4, 5	Ceiling	60	70	70
	Exterior Wall	30	35	35
6	Ceiling	60	70	70
	Exterior Wall	10	10	10

Table 3. Heating and Cooling Periods in Different Cities (Kuma et al., 2008)

	1 Sapporo, 2 Hachinohe	3 Sendai, 4 Toyama	4 Tokyo	5 Miyazaki	6 Naha
Heating Period	Jan.-May, Oct.-Dec.	Jan.-Apr., Nov.-Dec.	Jan.-Mar., Nov.-Dec.	Jan.-Mar., Dec.	
Cooling Period	Jun.-Sep.	May-Oct.	Apr.-Oct.	Apr.-Nov.	Jan.-Dec.

Table 4. AC Operating Details

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
AC ①	Living Room							■	■											■	■	■	■			6 Hours
	Master Room																						■	■		2 Hours
	Child's Room																									0 Hours
	The Others																									0 Hours
AC ②	Living Room							■	■	■				■	■			■	■	■	■	■	■			11 Hours
	Master Room																						■	■		2 Hours
	Child's Room																					■	■	■		3 Hours
	The Others																									0 Hours
AC ③	Living Room							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				15 Hours
	Master Room	■	■	■	■	■	■	■														■	■	■	■	11 Hours
	Child's Room																									0 Hours
	The Others																									0 Hours
AC ④	Living Room	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 Hours
	Master Room	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 Hours
	Child's Room	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 Hours
	The Others	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 Hours

■ AC on □ AC off

Effect Variation in Japanese Cities (Simulation Result 1)

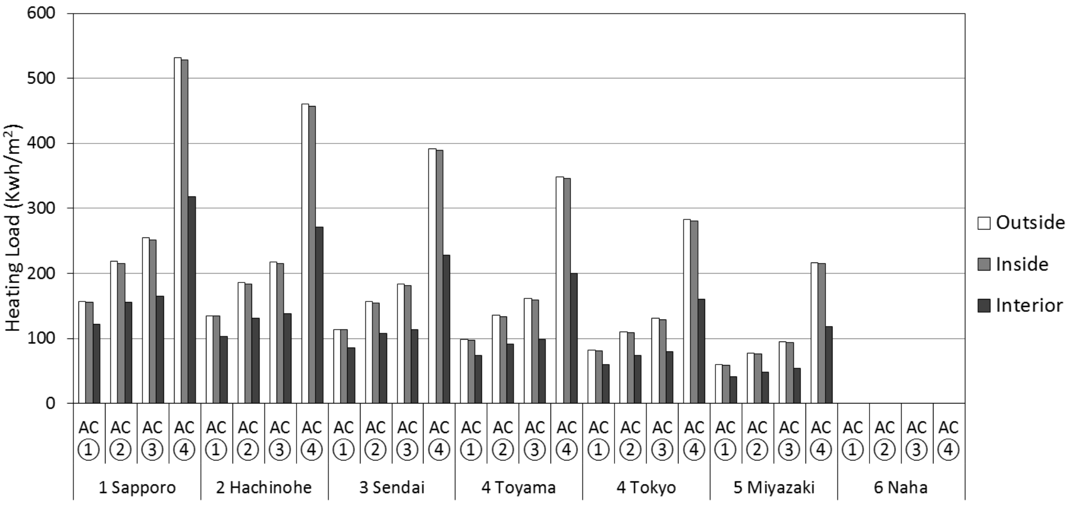


Figure 5. Heating Load in Seven Japanese Cites with all AC Usage Patterns

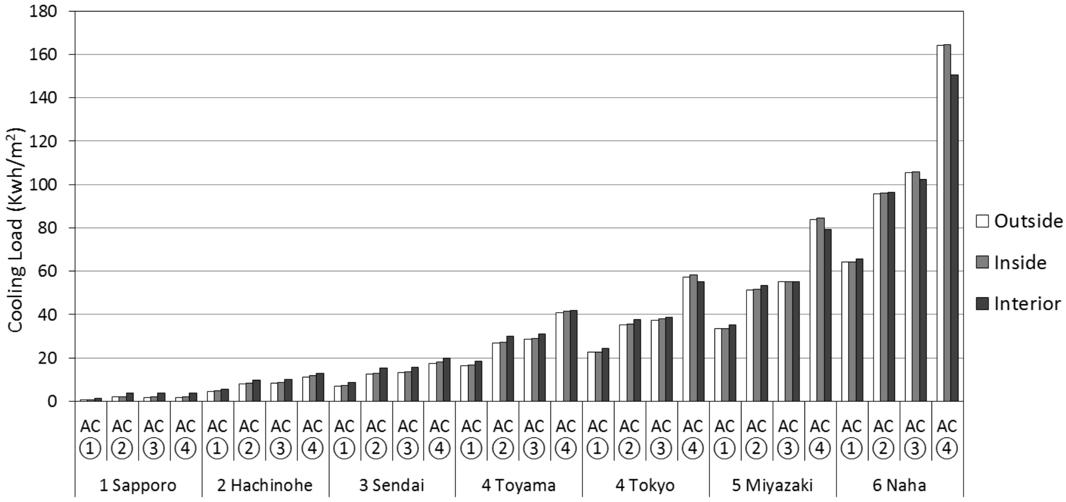


Figure 6. Cooling Load in Seven Japanese Cites with all AC-usage Patterns

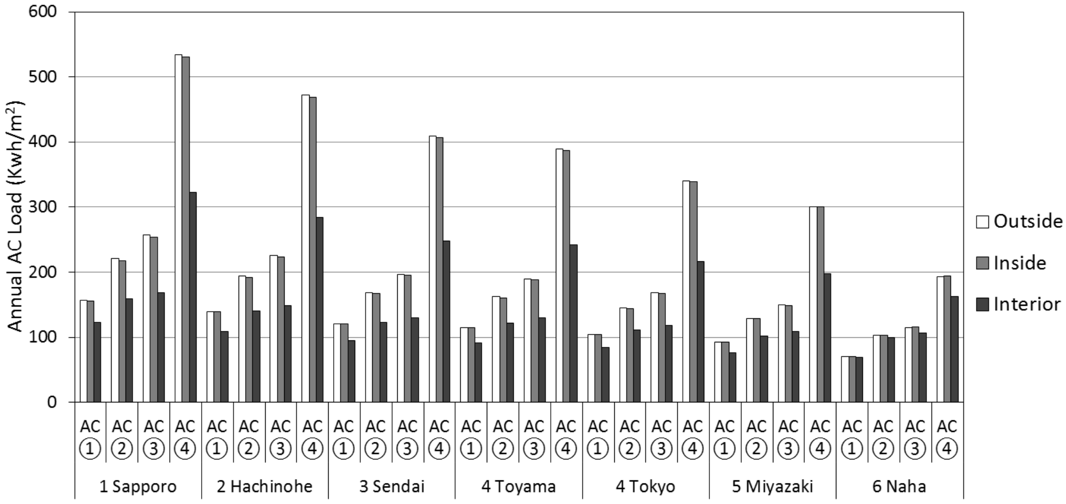


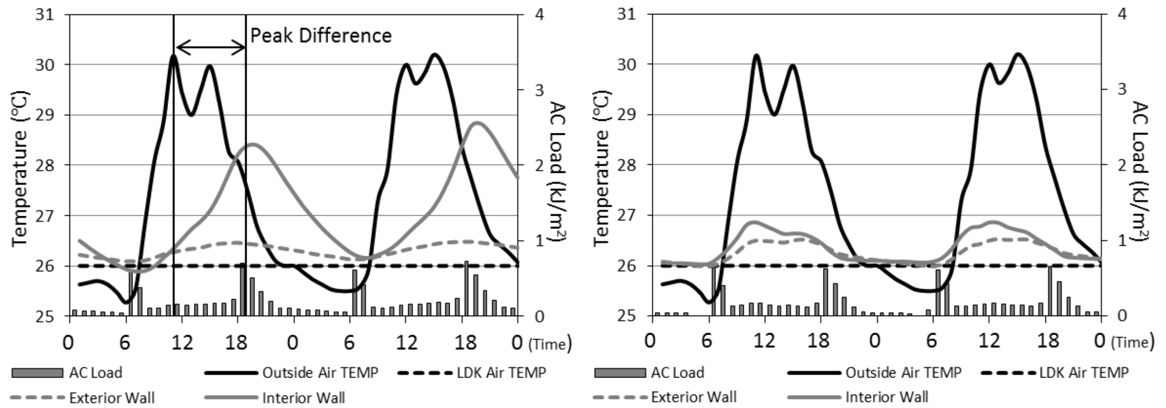
Figure 7. Annual AC Load in Seven Japanese Cites with all AC Usage Patterns

Figure 5 shows the comparison of heating load in seven Japanese cites with all AC usage patterns. Overall, heating load in warm city is lower than that in cold city. In the seven cities with four AC usage patterns, heating load of interior insulation unit is lower than that of outside insulation unit. The average decreased ratio is 29.7%. The highest decreased ratio is 45.5% in Miyazaki with using AC ④. Heating load of inside insulation unit is slightly lower than that of outside insulation. The averagely decreased ratio is 0.9%.

Figure 6 shows cooling load in summer in the units with varied conditions. Cooling load in north cities is lower than that in south cities. Cooling load in Sapporo is the lowest, and that in Naha is the highest. Cooling load of inside insulation unit is mostly higher than that of outside insulation unit, except using AC ① in Naha. Cooling load in inside insulation unit is averagely 3.7% higher than that in outside insulation unit. In interior insulation unit, cooling load is mostly higher than that in outside insulation unit. The highest ratio of the difference is using AC ① in Sapporo, cooling load of interior insulation unit is 56.3% higher than that of outside insulation unit. However, with using AC ④ in Tokyo, Miyazaki and using AC ③,④ in Naha, cooling load is lower in interior insulation unit than that in outside insulation unit. Generally, the differences between three insulation types are not as big as heating load in winter.

Figure 7 shows AC load in seven Japanese cities. In warmer cities, annual AC load is lower than that in colder cities. This is because heating load consists mostly of annual AC load. Annually, with the same AC usage pattern in a same city, AC load of apartment unit with outside insulation is higher than that of inside insulation unit. AC load of interior insulation unit is the lowest in the units with three varied insulation styles. AC load of inside and outside insulation units is very small. In all of the cases, inside insulation unit is averagely 0.5% lower than that of outside insulation unit. For comparison, AC load of interior insulation unit is averagely 25.8% lower than that of outside insulation unit. The highest ratio of AC load decrease between these two insulation styles is 39.7%, in Hachinohe, using AC ④. In Sapporo, almost 100% of AC consumption is heating. And the heating load in Hachinohe and Sendai is over 90% of annual AC load. On another hand, in Naha, annual ratio of heating load is under 15%. How to reduce heating load in northern cities is an important mission.

Effects of Heat Capacity on Indoor Thermal Environment (Simulation Result 2)



Outside Insulation **Interior Insulation**

Figure 8. Cooling Load and temperature change in two summer days with outside insulation and interior insulation from 15th to 16th, August, use AC ④, in Tokyo

For demonstrating the effect from the high heat capacity walls, the comparsion of indoor air temperature and wall surface temperatures are carried out in the figure 8. The peak of outdoor air temperature is observed between 12am to 15pm. In outside insulation, the peak temperature of exterior and interior walls surface is observed around 18pm, about 3 to 6 hours later than the outside air temperature. This is because of the high heat capacity of interior building materials. In the interior insulation unit, the peaks of interior surfaces are the same of outside air temperature, and the temperature of interior wall surface temperature is about 1.5 ℃ lower than that in outside insulation unit. Therefore, low heat capacity of walls creats a controllable indoor thermal condition, and reduces cooling load in summer days.

CONCLUSION

In this paper, an innovative insulation style of interior insulation is proposed and investigated. A calculation of heat loss in three types of insulated units demonstrated the mechanism of heat loss through Heat Bridge, and the advantage of interior insulation. Heat Bridge in outside and inside insulation units is distinctly effect to the building thermal performance, and the heat loss through Heat Bridge is avoided by interior insulation implement. Subsequently, AC load and thermal comfort of apartment unit with three insulation types are compared and discussed with numerical simulation. In both of heating and cooling seasons, indoor air temperature of outside insulation unit is the most stable. In cooling season, indoor temperature of the interior insulation unit is the lowest in three insulation type units when the cooling is not in use. Look at the AC load, it is various in different cities and seasons. Compare to outside and inside insulation units, annual AC load of interior insulation unit is the lowest in all of the conditions.

In terms of indoor thermal environment, outside insulation is the best to stabilize room temperature. However, in winter, the temperature of indoor wall surfaces in outside insulation unit is much lower than that in interior insulated unit. This leads to an uncomfortable indoor environment and high heating energy comsumption.

Finally, as we discussed about the features of the three insulation styles, the advantage of new proposed interior insulation is demonstrated, and the advantages and disadvantages of these three insulation styles are verified and expounded. Various factors should be considered such as regional characteristics, insulation efficiency levels and design conditions, before the building will be built.

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Contemporary use of earthen techniques in Colombia: Thermal performance of domestic and non-domestic building typologies

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ABSTRACT

Buildings consume energy in different ways. In the last decades, particular consideration has been given to buildings' operational energy such as heating, cooling and lighting energy demand. However, with the increased environmental awareness and further advances in the regulatory frameworks globally, the energy consumption embedded in the material extraction and in the construction process is becoming increasingly relevant. The hypothesis of this paper is that naturally sourced, low cost and low embodied energy materials can be used as an alternative to conventional ones in Colombia. An analysis of earthen techniques such as Stabilized Rammed Earth (SRE) and Compressed Stabilized Earth Blocks (CSEB) is made in comparison to conventional massive and aerated fired bricks in terms of their thermal performance. Fieldwork undertaken at an earthen building is presented, informing on the thermal behaviour of Rammed Earth for wall construction. Furthermore, the thermal inertia of earthen materials is analysed for both domestic and non-domestic building typologies, through dynamic thermal simulation. The applicability of earthen mass in different envelope components is assessed defining design guidelines for its successful use in the specific climate and context of Bogotá.

Keywords: stabilized rammed earth (SRE), compressed stabilized earth blocks (CSEB), natural fibres, thermal mass, heat capacity, diurnal fluctuation.

INTRODUCTION

The practice of sustainable design is highly related with the choice of materials since it deals with both embodied and operational energy. Traditional techniques have proven to be an alternative for reducing the embodied energy of buildings still showing potential for improving the operational one. In Colombia, these techniques are being reconsidered after several decades of urban development based on industrialized materials. The main question that is addressed in this paper is whether earthen materials can perform as an alternative to conventional ones. The focus of the article is on the thermal performance of earthen techniques such as Stabilized Rammed (SRE) and Compressed Stabilized Earth Blocks (CSEB) in comparison to conventional fired bricks. For this purpose, a first approach to earthen materials is presented through the study of earthen composites. Furthermore, fieldwork undertaken in an earthen building establishes an introduction to the thermal performance of these materials. In addition, Bogotá's climate was defined and basic questions regarding thermal performance, passive strategies and envelope specification of domestic and non-domestic building typologies were answered through simulations in EDSL TAS establishing applicability guidelines.

EARTHEN COMPOSITES

Earthen constructions present structural limitations. In fact, while the thickness of conventional wall construction made out of brick or concrete is about 30 cm, a wall made out of rammed earth is normally around 50 cm thick. Earthen composites were assessed in terms of their conductivity, volumetric heat capacity and compressive strength as shown in Figure 1. It can be seen that the potential of fibres is from their insulation properties, which is due to their low conductivity values about 0.05 W/mK. Thus, they could be used as insulations boards for floors, walls and roofs. For thermal purposes, the combination of loam and fibres shows high potential due to low conductivity values about 0.2 W/mK, appropriate for insulating purposes, and relatively high volumetric heat capacity between 1100 and 1790 kJ/m^3.K convenient for thermal mass strategies can be achieved. In the case of stabilized earthen composites, it was shown that the structural limitations of the material could be addressed. In fact, the SRE can achieve half of the structural performance of a conventional brick and the CSEB can achieve about the same compressive strength. In addition, both proved to have the highest Volumetric Heat capacity reaching values of 1900 kJ/m^3.K. From the above, further analysis considered CSEB and SRE materials for thermal mass strategies, and fibres for insulating purposes.

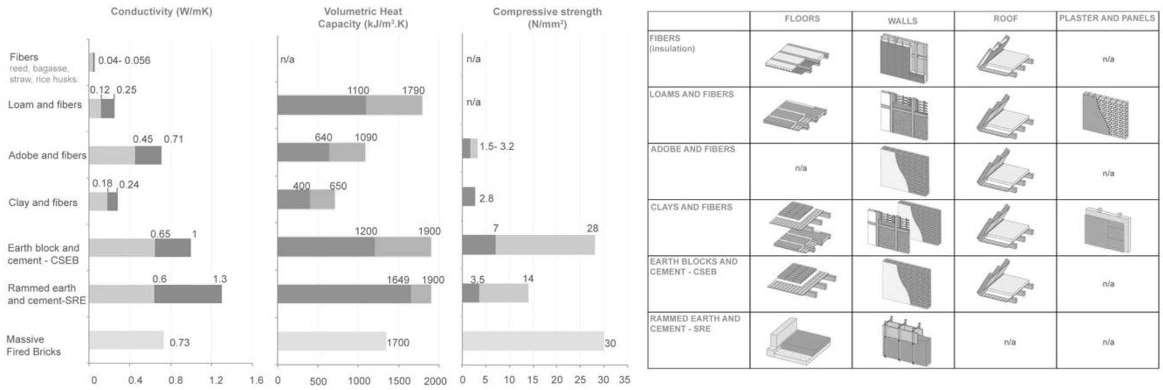


Figure 1. Earthen composites' properties and possible applications. Adapted from: Ashour et al. (2010); Lertwattanaruk and Choksiriwanna (2011); Goodhew and Griffiths (2004); Morton, (2008); Walker et al. (2005) Hall and Allinson (2008) and Schreckenback, (2004).

BREATHABILITY

Another aspect of these materials that adds quality to them is their breathability. May (2005) defined the latter as the ability of materials to absorb and release water as vapor (hygroscopicity) andthe ability to absorb and release water as liquid (capillarity). The relevance of the breathability of a building is the fact that the moisture affects building's thermal performance as well as the health of the occupants. It has been demonstrated through monitoring that earthen masonry has potential to regulate the internal relative humidity of a building between 40 and 60 %6 (Morton, 2008).

CASE STUDY

A buildingwas studied to understand the performance of earthen construction by installing dataloggers in the internal space, buffer space and in the exterior of a rammed earth building.

The case study presented corresponds to a circular auditorium with a double double-layered façade where the inner façade is made out of rammed earth. The theatre is an auditorium with capacity for 200 people (Figure 2). Depending on the event, the occupancy could vary between 10 to 200 people. During the visit, lectures took place between 9:00 h and 18:00 h and it was intermittently occupied by 20 people.

Set up and procedure: Three data loggers were placed during the visit in order to understand the relation between the external climatic conditions, the southern buffer space and the interior of the auditorium. The monitoring was made for a period of 24 hours between May 26th and May 27th 2012. Moreover, data were provided by local engineers regarding monitoring made in the walls for the day of the visit.

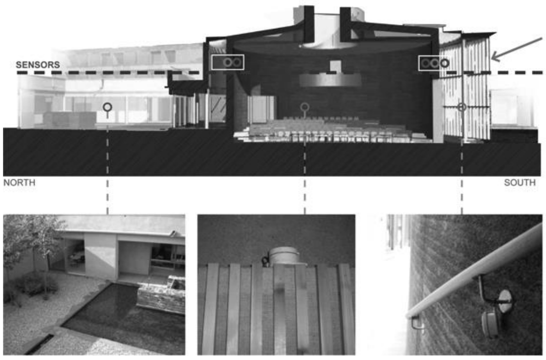


Figure 2. Case study images.

Results from data loggers: Figure 3 shows the temperature and relative humidity results obtained from the three different data loggers installed. There is a grading in the temperature from the outside, the buffer space and the inside of the auditorium. While the night temperature fluctuated by 12 K, it remained stable in the buffer space around 21 ºC and inside around 22 ºC. Moreover, at the coldest time of the night when the temperature was 16 ºC, the internal temperature was higher by 7K. During the morning time, around 9:30 h, the outside temperature increased significantly, while the internal temperature in the buffer space and auditorium remained constant between 21 and 22 ºC for a period of three hours, before the door was opened and the internal temperature reached the external conditions.
In regards to the relative humidity, there is an increasing relation from the interior of the auditorium to the buffer space and the exterior. While the external relative humidity reached levels of 90 %, it remained constant in the buffer space and the auditorium around 50 and 55 % respectively. Although there was a drop in the humidity levels in the buffer space around midday, the internal relative humidity remained stable inside the auditorium around 55 %.

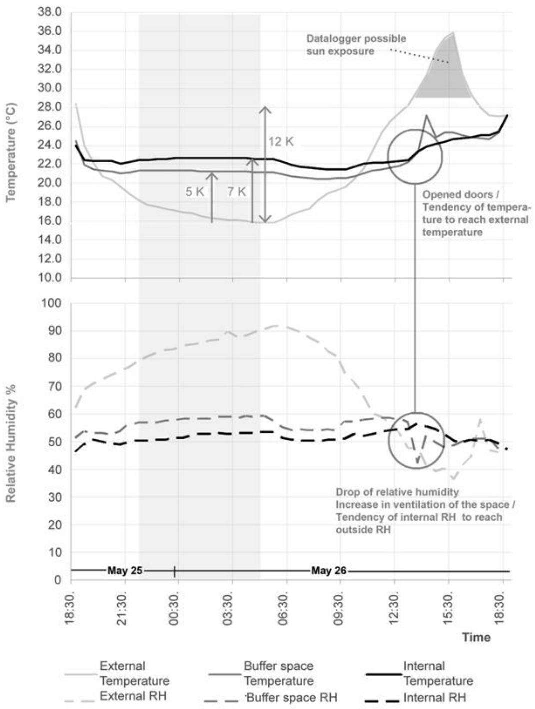


Figure 3: Air temperature and relative humidity from dataloggers.

CLIMATE

A weather file for Bogotá from Meteonorm 6.1 was analysed.

- Temperature: the mean temperature in Bogotá is constant throughout the year with a value around 13 ºC achieving a mean minimum and maximum values 7 ºC and 19 ºC respectively. In a typical day in June, diurnal fluctuations can be as high as 15 K with temperatures between 6 ºC and 21 ºC.

- Humidity: although relative humidity can achieve values up to 80 %, the humidity is not an issue since the moisture content remains within a range of 4g/kg and 12 g/kg which is within the comfortable range (Szokolay, 2004).
- Solar radiation: in regards to the mean hourly solar radiation values for different orientations, it can be seen that east and west vertical planes are likely to receive constant solar radiation throughout the year around 2.5 kWh/m^2. In contrast, north façade's radiation varies, being constant between April and September about 1.2 kWh/m^2 achieving up to 2.4 kWh/m^2 for the rest of the year.

THERMAL COMFORT

Thermal perception was understood through the notion of thermal neutrality (Tn), which considers physiological factors of acclimatization. The adaptive model by Aluciems (1981) can be defined as follows: Tn = 17.6 + 0.31 Toavg; where Tn= neutral temperature and Toavg= mean outdoor temperature. In addition, adding or subtracting 2.5 K defines a comfort range with 90 % of acceptability. Conversely, adding or subtracting 3.5 K, a comfort range with 80 % of acceptability is defined (Figure 4).

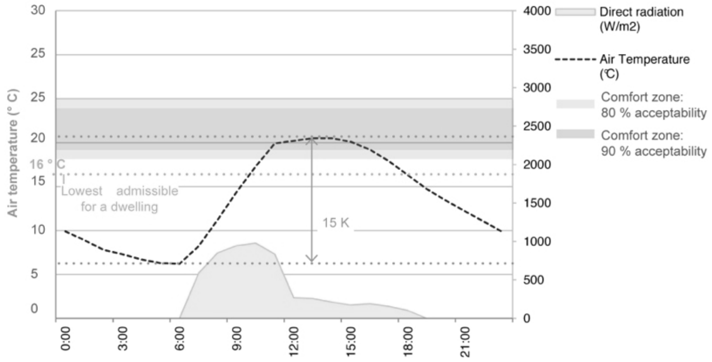


Figure 4. Diurnal fluctuations and thermal comfort parameters, June the 14th.

HYPOTHESIS

In regards to the domestic building typology, the following hypothesis can be established:

- Passive heating requires no more than a well-oriented and sized window (Szokolay, 2004). West seems to be the most desirable orientation.
- Due to diurnal fluctuations, thermal storage mass maybe required. This depends on a careful distribution of the thermal mass.

As far as non-domestic and high internal gains building typologies are concerned, the following could be extracted:

- For cooling purposes in high occupancy buildings, thermal mass can be appropriate since it would perform as a heat sink.
- The climate analysis suggests north orientation as the most suitable.

As diurnal temperature fluctuations are as high as 15K, the thermal mass could work together with natural and/or night ventilation strategies (Baker, 2009).

THERMAL ANALYSIS

An analysis regarding the thermal performance of domestic and non-domestic building typologies was carried out aiming to answer the following questions:

- How do earthen materials perform compared to conventional ones?
- How much earthen mass is required to achieve a significant heat storage effect?
- In what position is earthen mass most beneficial?
- For building programmes with potential overheating issues, can ventilation strategies improve the thermal mass effect of earthen materials?

DOMESTIC BUILDING TYPOLOGY

A stand alone and west oriented dwelling with an area of 30 m^2 was defined and the input parameters for simulation can be seen in Table 1. The dwelling was assumed to be occupied by two adults between 18:00 and 6:00 in weekdays and from 16:00 to 9:00 h in weekends. In addition, Table 2 shows the parameters considered for the different materials defined in the model

Table 1: Initial input parameters for the simplified model.

Geometry		Internal gains		
Area	30 m2	Equipment	7.4 W/m2	
Volume	90 m3	Set back value:	1.0 W/m2	
Window area	4.5 m2	Lighting:	1.4 W/m2	
External wall area	64 m2	Occupancy(x2)	6.4 W/m2	
Window to floor ratio	15%	**Infiltration rate**	0.5 ACH	
U Values	W/m2.K	**Schedules**	Weekday	Weekend
Aerated fired Brick Walls:	1.8	Equipment	5:00 - 7:00	8:00 to 9:00
Fibre cement roof:	5.7		18:00 to 22:00	16:00 to 23:00
Ground floor:	0.25	Lighting:	same as above	18:00 to 22:00 h
Windows (SG)	5.6	Occupancy(x2)	18:00 to 6:00	16:00 to 9:00 h

Table 2: Material properties.Adapted from Goodhew and Griffiths (2004); Hall and Allinson (2009); Ashour et Al. (2010).

	Density kg/m3	Specific Heat KJ/kg.K	Conductivity W/m.K	Volumetric Heat Capacity kJ/m3.K
Lightweight	500	0.176	0.14	88
Aerated Fired Bricks (AFB)	1000	0.84	0.3	840
Fired Brick	1700	0.8	0.73	1360
SRE (7% cement)	1900	0.868	0.643	1649
CSEB (5% Cement)	1900	1	1	1900
Loam/ Earth plaster	1790	1	0.25	1790
Reed mat (20 or 50 mm thick)	190	-	0.056	-

Roof: Since earthen roofs are commonly supported by slatted timber and reeds, the effect of these was first assessed. Then, the progressive addition of external earthen mass was tested. Figure 5 shows that reed insulation (run 2) improved thermal conditions and the percentage of hours that the yearly resultant temperature was between 90 % and 80 % of acceptability increased from 21% and 30 % to 27% and 40% respectively. Moreover, the external addition of earthen mass did not show any significant improvement and above 10 cm thickness, the benefit is negligible. Up to such thickness, the improvements are mainly due to an U-Value reduction to 0.7 W/m^{2}K.

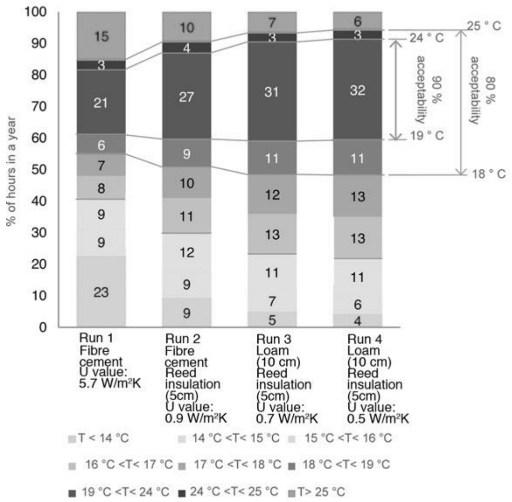


Figure 5: Resultant temperature frequency distribution in a year for different roofs.

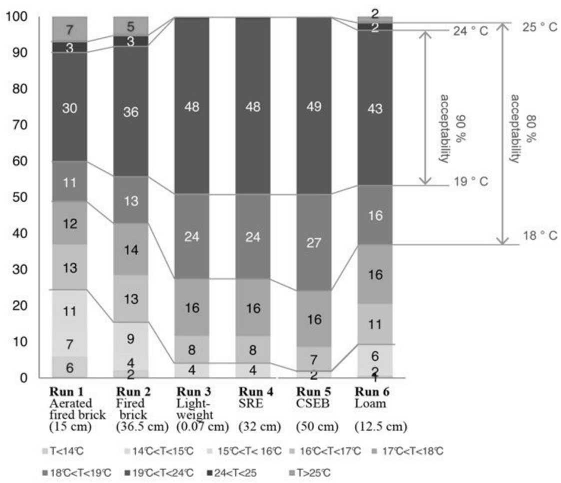


Figure 6: Resultant temperature frequency distribution in a year for different materials tested with same U value.

Material comparison fixed U-Value: In order to assess only the Volumetric Heat Capacity (VHC) and the effect of mass and given the fact that the U-Value depends on the wall thickness and on the material conductivity, U-values were set to be the same (1.5 W/m^{2}K). Figure 6 shows that all-massive construction materials have a similar performance achieving 90% of acceptability for 49 % of the year. In addition, the AFB walls would generate the highest diurnal resultant temperature fluctuation in June 14 th about 10 K while the lightweight construction and CSEB would fluctuate by 8K and 2.5 K respectively. This can be partially explained by the fact that the effect of mass of thick wall constructions is required to achieve the set U-value.

Earthen mass: the effect of mass has potential for improving internal comfort and is likely to be most effective when coupled with internal spaces (Baker, 2009). In order to assess the required quantity, earthen mass was progressively added on internal surfaces. Loam was used for ceiling, CSEB for walls and SRE for floors. It was shown that the dwelling's thermal performance is sensible to the amount of applied mass on internal surfaces. By increasing envelope's elements by 20 cm, the percentage of hours within 80 % and 90 % of acceptability increased from 33% to 42 % and from 49% to 74% respectively. Nevertheless, due to construction feasibility, a maximum wall thickness of 35 cm was considered admissible. This corresponds to the addition of 15 cm of SRE and loam on floors and ceiling respectively. The addition of mass reduced the internal fluctuation from 6K to 2K in a typical day.
The window sizing and the amount and position of insulation were optimized by adjusting the window to floor ratio to 30% and 5 cm of reed insulation placed outside the wall would optimise the performance (Walls U-value = 1.1 W/m2. K). With these variations on the simplified model, further analysis was undertaken.
Earthen mass position: a concern for architectural design is the position where the thermal mass is most effective in a building. This was assessed by changing one envelope element at the time (improved roof, floors and walls) and then looking at the overall effect of the heavyweight construction from the previous analysis. For the geometry considered, the best improvements were the earthen roof and the earthen walls showing a decrease in the percentage of overheating hours, from 19 % to 10% and 9% respectively. Moreover, the use of mass for internal partitions showed a significant improvement increasing the percentage of hours within 80% of acceptability by 14 %. Overall, the extensive use of mass increased the percentage within 90% and 80% of acceptability to 67% and 86% respectively. Figure 5 shows the resultant temperatures for the base case (run 1) and the optimized scenario with extensive thermal mass (run 6). For this case the resultant temperature fluctuates by only 4K in a typical week while lightweight construction would generate fluctuations of 20 K (Figure 7). This is explained by the fact that the largest the surface on which it is applied, the most effective is the thermal mass (Balcomb, 1983).

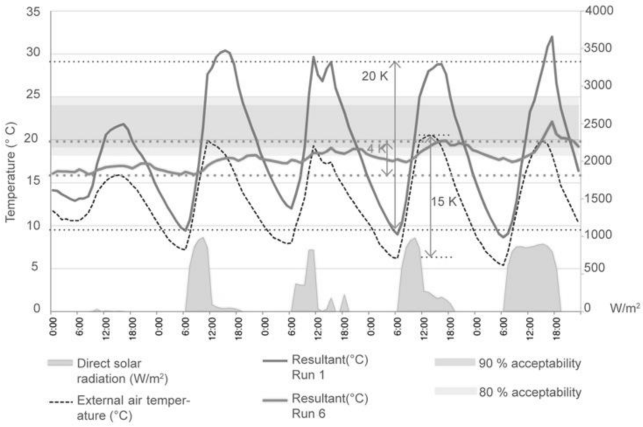


Figure 7: Resultant temperatures between June 11 th and 15 th for base case and heavyweight constructions, domestic building type.

NON-DOMESTIC BUILDING TYPOLOGY

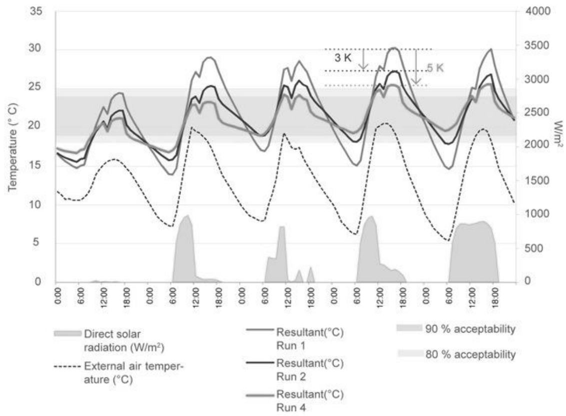
Other building programmes such as schools may suffer from overheating issues and could benefit from the mass effect provided by earthen materials. A simplified model was simulated considering the parameters listed in Table 3. The classroom is assumed to be occupied by 32 people from 8:00 to 18:00. During lunch time (13:00 h to 14:00 h), half of the occupancy is assumed. The classroom is oriented north and south walls are shaded. The main focus of the simulations was to look at the amount of mass required in a high occupancy programme and the potential ventilation may have to improve the mass effect for cooling in Bogotá.

Table 3.Initial input parameters for classroom-simplified model.

Geometry		Internal gains	
Area	72 m2	Equipment	6 W/m2
Volume	216 m3	Set back value:	1.0 W/m2
Window area	10.8 m2	Lighting:	3 W/m2
External wall area	45.6 m2	Occupancy(x32)	45 W/m2
Internal wall area	43.2 m2	**Infiltration rate**	0.5 ACH
WFR	20%	**Fresh air req**	4.5 ACH
U Values	W/m2.K	**Schedules**	Weekday
External walls	1.9	Equipment	8:00 - 18:00
Roof:	0.7		
Ground floor:	0.25	Lighting:	6:00-18:00
Windows (SG)	5.1	Occupancy(x32)	8:00 to 18:00

Earthen mass: By changing the wall construction from lightweight to heavyweight, the percentage of overheating hours during occupancy decreased from 37 % to 12 %. The addition of internal mass proved to be effective up to 10 cm thickness for floors and ceilings and 30 cm thick walls. Figure 8 shows the resultant temperatures during a week from lightweight walls, to heavyweight walls and the optimal internal addition of mass. It can be seen that the second (run 2) reduced the temperature peak by 3K compared to the first for the warmest day of the week. Moreover, the addition of internal mass (run 4) reduced this peak by 2K compared to the second.

Ventilation: Natural ventilation and night ventilation could work jointly with thermal mass (Baker, 2009). Simulations aimed at assessing the impact of multiple ventilation rates as well as night ventilation potential. It was shown that the increase of ventilation rate during the day would reduce the percentage of hours within 90 % of acceptability. In contrast, ventilating at 4.5 ACH during occupancy and doubling the rate during the night allowed to increase the percentage of hours within 90 % of acceptability from 84 % to 86 %. In addition, it was shown that night ventilation has potential for reducing the resultant temperature's peak by about 2K compared to the initial case (Figure 8 b).



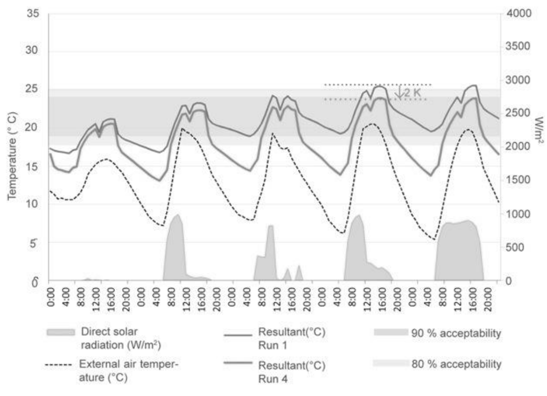


Figure 8 a: Resultant temperatures between June 11th and June 15 th for base case, heavyweight walls and optimal case**.**

Figure 8 b: Resultant temperatures between June 11th and June 15 th for base case and optimal ventilation strategy.

CONCLUSION

The questions answered in this paper aim to conceive guidelines for the applicability of traditional building techniques in a contemporary context. Earthen composites made with low cement proportions were mainly considered. Material comparisons, envelope specifications, thermal mass and ventilation strategies framed the contemporary application of traditional earthen materials for domestic and non-domestic buildings. It was proven that locally sourced techniques such as compressed stabilized earth blocks could perform thermally as well as conventional bricks. Moreover, the thermal mass strategy proved to be more effective for cooling than for heating purposes in Bogotá. Further research should consider the effect of earthen techniques in terms of embodied energy and cost in order to reach a holistic assessment of the material. In addition, considering the hygrothermal properties of earthen constructions, the different techniques studied in this work should be analysed and compared in terms of their humidity balancing potential and condensation risk.

ACKNOWLEDGMENTS

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Session 5A : Lessons from vernacular architecture

PLEA2014: Day 2, Wednesday, December 17
11:30 - 13:10, Auditorium - Knowledge Consortium of Gujarat

Comparative Thermal Performance of Vernacular Houses at Lucknow: A Quantitative Assessment & Dominant Multiple Strategies

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ABSTR ACT

This study focuses on the comparative thermal performance of a selection of cases from three distinct generic types of vernacular houses at Lucknow, a culturally & architecturally renowned city in the Gangetic plains of Northern India. The objective of the study has been to evaluate the core urban courtyard houses, colonial adapted bungalows and semi-rural mud houses at Lucknow to ascertain which type(s) have responded to the prevailing climate better than others and what factor(s) or strategies may be contributing for its (their) improved performances. Most significantly it has aimed to search for emergent energy efficient principles applicable to the region's composite climate characterised by hot-dry summers, cold winters and intermediate warm-humid monsoon season. This has been pursued firstly by an in-depth study of deviant cases within each generic house type with respect to Lucknow's composite climate assessing their anticipated performances. Later simultaneous monitoring of indoor temperatures and humidity in identified periods of each season has been analysed among these cases followed by their testing against the adaptive model of thermal comfort prescribed by Nicol and Humphreys. Moreover their simulations on Ecotect software have been examined and calibrated making them suitable for extended research. Conclusively, this study has acknowledged the significance of a combined chemistry of varied strategies & sub-strategies functioning together in each house for effective thermal response in this region. Furthermore, it has given a range of multiple tactics to fall back upon instead of a myopic view of just orientation or thermal mass or others & more importantly it has substantiated the role of ventilation & air movement for the favourable thermal performance of a built envelope. As a whole this research has been useful in deriving inexpensive passive strategies useful for Lucknow also resulting in principles and recommendations suitable for the composite climate of the region.

BACKGROUND

The significance of learning from the vernacular has been corroborated by a number of scholarships that have also ascertained that, their responses to prevailing climatic conditions have been favourable. These lessons are even more meaningful in the contemporary Indian context with low energy resources and the unremitting escalating needs of an exploding population. Moreover learnings from the Indian vernacular have also established their effective thermal performances with respect to existing environments especially the hot-dry and warm-humid climates. Lucknow, is a culturally and architecturally rich North Indian city located in the Gangetic plains, experiencing a composite type climate that necessitates varied responses from a built form all through the year. Furthermore the city fabric consists of broadly three vernacular house types comprising of the core urban courtyard type, bungalow type and the semi-rural mud house type, within its precincts, that have not yet been examined for their thermal responses. It is interesting to note that all these generic house forms are distinct and varied from each other and yet seem to be thermally comfortable in the varying composite climatic conditions of the region.

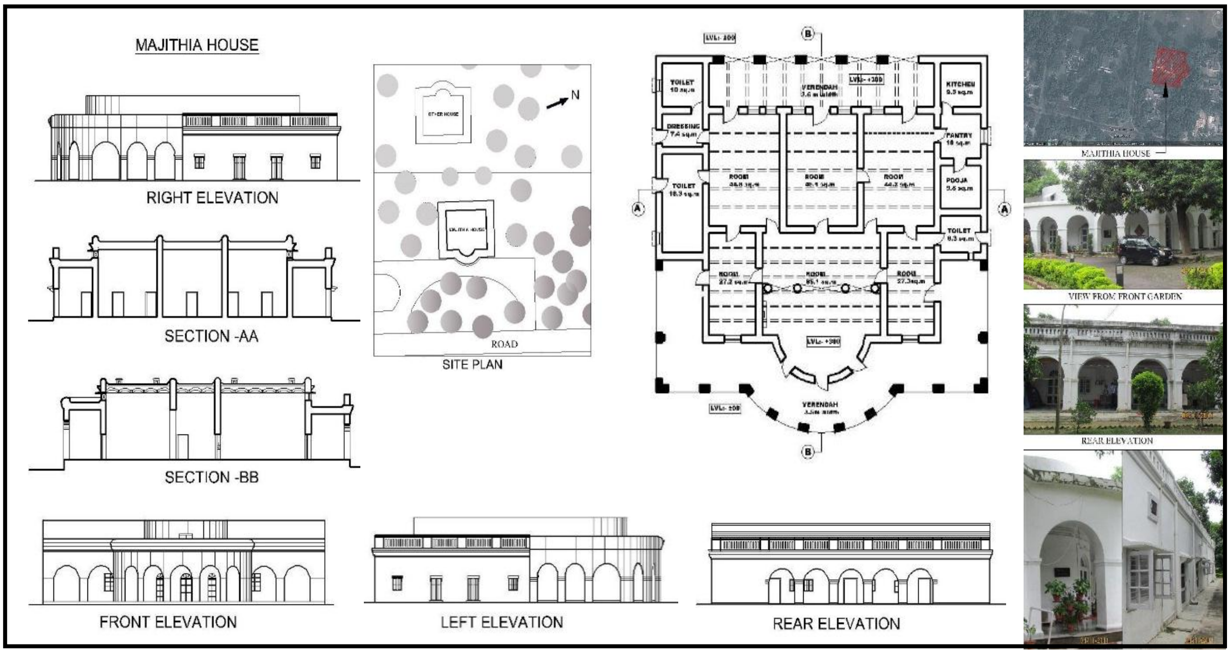
THERMAL COMFORT: SELECTED MODELS & METHOD:

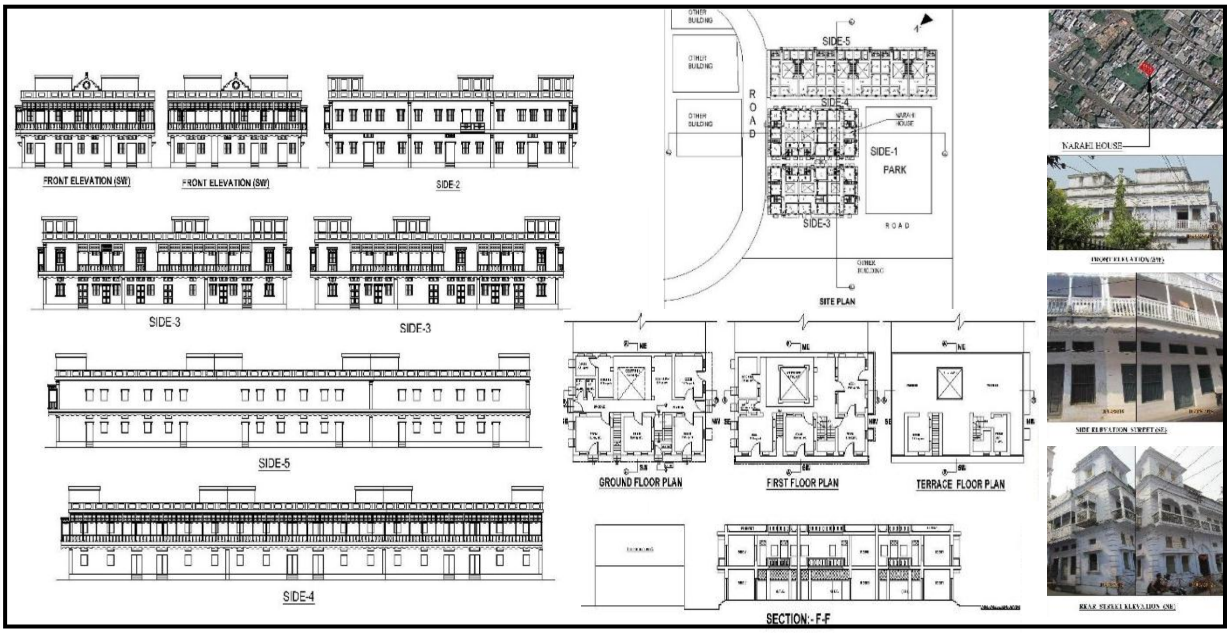
A review of previous scholarships has acknowledged the role of thermal comfort as most significant within a built form that could be defined as a condition expressing satisfaction with the thermal environment. Moreover the scientific interventions for assessment of thermal comfort have included various models like the steady state (ASHRAE 55), PMV (Fanger) beside other empirical & analytical indices. These have led to the significance of adaptive model of thermal comfort which relates the outside prevailing conditions to the indoors, thus establishing that people have remained comfortable approximately to the average indoor temperature they encountered. Equations for the same have been derived by Humphreys & Nicol as $Tn = 12.1 + 0.534^* Tm$ and $Tn = 17 + 0.38^*Tm$ respectively, where Tn was the predicted indoor comfort temperature directly determined by the outdoor temperature of a place, and Tm that was the monthly mean outdoor temperature (Auliciems). These models gave a flexible thermal comfort band of 5°C to 7°C in which a person could become comfortable by short term actions or long term acclimatization validating their utility in the diverse tropical climate of the Indian Subcontinent simultaneously reducing the energy demands created by uniform steady temperature standards. Furthermore, the recognised most controllable factors affecting the thermal performance of a building envelope within the architectural premise include its Siting, Location, Orientation, Form and Massing, Spatial Organisation, Open Built Distribution, Material and Construction Techniques besides special elements responsive to existing climatic conditions. Accordingly they shall assume a significant role in selection of cases for study and the subsequent extrapolation of passive strategies.

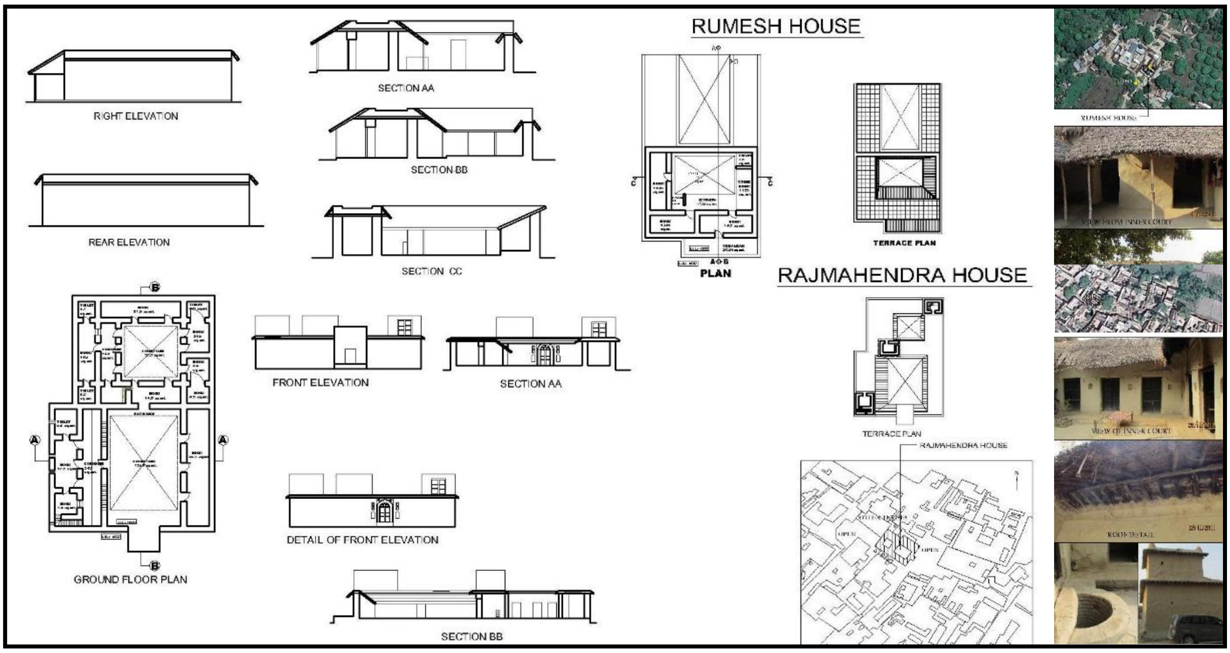
LUCKNOW: CONTEXT CLIMATE & SELECTED STUDIES:

Lucknow city is regarded as one of the “finest cities of North India both in the architectural and cultural context” (Siddiqui 27). As a spontaneously accretive grown city, it is more a consequence of the various layers of development added to it by the diverse rules and colonisations due to which the city’s morphology is an amalgamation of organic & geometric parts. Broadly three types of house forms have developed, the most significant of them being the city courtyard houses, inhabited both by Hindus and Muslims; the bungalows that have been colonial adaptations by British; and the semi- rural mud houses present on the fringes of the city. While most of the courtyard houses are introverted and situated in the old city areas accessed by winding streets among *mohallas*, some later ones have formed part of newly well-defined settlements. The bungalows on the other hand have constituted of more formal well-defined spaces with extroverted arrangements set amidst large secure compounds within well-maintained cantonment or similar precincts. In contrast the semi-rural mud houses have existed as semi-introverted courtyard houses in informal clusters with an agrarian population of informal usage patterns.

All these house types have evolved in diverse contexts and conditions but have co-existed in the city for more than hundred years. Furthermore they have been built after numerous checks and balances making them vernacular in the true sense of the word. The core urban courtyard houses with shared walls have one or two courts with a single bay of rooms around it opening to narrow shaded streets within dense built contexts. Distinctly the Muslim houses have had two courtyards segregated for both men and women while the Hindu houses possessed a single courtyard both utilized for similar informal activities. Of introverted centripetal organisation, with thick lakhori brick, surkhi lime construction their roofs have been made of timber joists or jack arches. Within these, four variations were selected for the study namely Farangi Mahal house, Jannat Ki Khirki, Kaiserjahan house and Narhai house.The colonial adapted bungalows being detached monolithic units have centripetal extroverted configurations well lighted and exposed to the large open environment around them. These are made of thick walls of brick, surkhi, lime mortar and are usually single storied with flat jack arch with varied heighted roofs and verandahs in strategic directions. Within these, three variables in form of Majithia house David house and Rachna house have been selected as cases for examination. The semi-rural mud houses were semi-detached houses in clustered formations on large vegetated sites. Consisting of singly banked rooms around courtyards with transitional verandahs the selected cases consisted of the Pradhan house, Rumesh house, small mud house & Rajmahendar house. It is to be reiterated here that while the three types of


MAJITHIA HOUSE
RIGHT ELEVATION
SECTION -AA
SECTION -BB
SITE PLAN
ROAD
FRONT ELEVATION
LEFT ELEVATION
REAR ELEVATION
VERENDAH
MAJITHIA HOUSE
VIEW FROM FRONT GARDEN
REAR ELEVATION


FRONT ELEVATION (SW)
FRONT ELEVATION (SW)
SIDE-2
SIDE-3
SIDE-3
SIDE-5
SIDE-4
SIDE-5
SIDE-4
SIDE-1
PARK
SIDE-3
ROAD
SITE PLAN
NARAHI HOUSE
GROUND FLOOR PLAN
FIRST FLOOR PLAN
TERRACE FLOOR PLAN
SECTION:- F-F


RUMESH HOUSE
RIGHT ELEVATION
REAR ELEVATION
SECTION AA
SECTION BB
SECTION CC
PLAN
TERRACE PLAN
RAJMAHENDRA HOUSE
FRONT ELEVATION
SECTION AA
GROUND FLOOR PLAN
DETAIL OF FRONT ELEVATION
SECTION BB
TERRACE PLAN
RAJMAHENDRA HOUSE

house forms at Lucknow were already generically different in terms of organisation & siting the variables amongst each case varied in terms of shared walls; orientation; fenestration percentage; Courtyard proportions and massing. The objective of the selection of the cases was to ascertain the role of specific factors in the varying thermal performances of houses within one generic type and among diverse types.

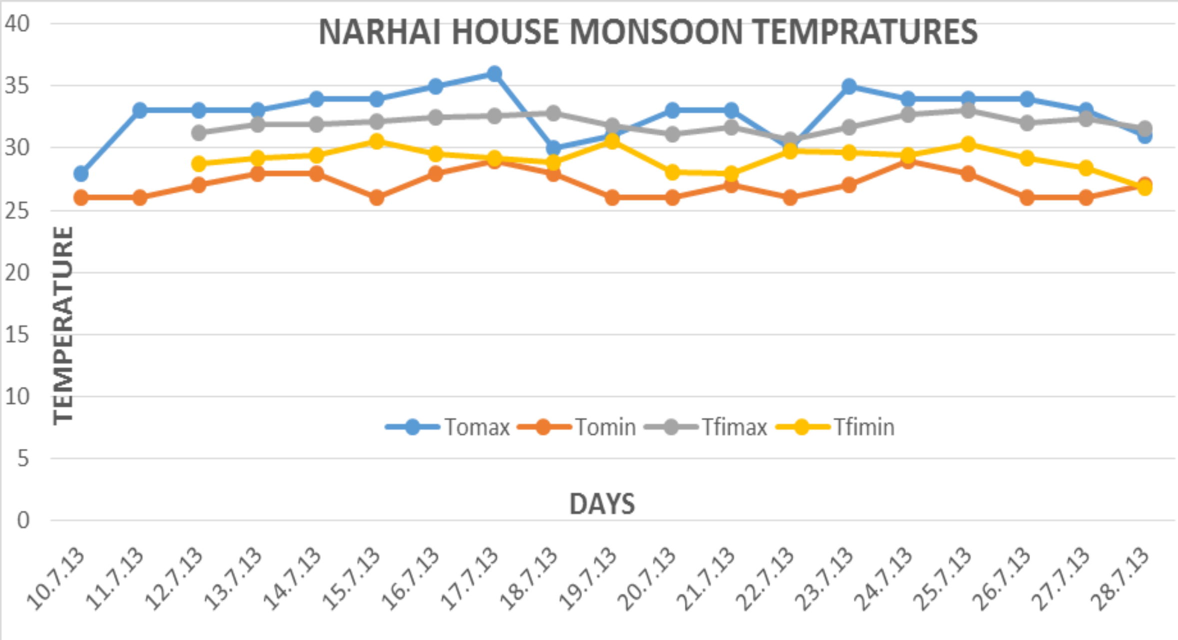
TOOLS & TECHNIQUES:

An in-depth critical review of utilised procedures and techniques for assessment of thermal performance of buildings all over the world was done to arrive at a comprehensive methodology for the study. These included theoretical studies without on-site documentation by Nevins & Dabaieh ; extensive site analysis with some numerical simulations by Ford & Associates, Vinod Gupta, Ashok Lall and Campos among others; on –site monitoring with extensive site- study by Brian Ford, Kotharkar, Ahmad and Fanchiotti; simulations & site studies by Kanika Agrawal, Antarikananda, Avlokita Agrawal, Haschem and Alanzi; on-site monitoring with simulations by Arvind Krishan, Young and Summers Francoise amid others. The simulating software was selected after assessing the reviews of Crawley, Ling and Summers amid others. Subsequent to the systematic analysis the methodology devised for this study was all inclusive, incorporating a detailed recording of the selected houses being variables of each generic type of house form at Lucknow. The expected thermal performance of each study was evaluated for each case against theoretical parameters after which an onsite simultaneous monitoring by Hobo Data loggers was conducted in the living rooms of all the houses for similar periods all over the year. These results were plotted on the predicted comfort equations by both Humphreys and Nicol for the assessment of recorded data of all selected cases. Concurrently Ecotect models were developed for all cases with simulation for critical discomfort periods and tested for varying parameters. Later the results from monitoring & Ecotect were put together and analysed to assess the performance of each case to establish principles useful for this region.

ANALYSIS OF DATA & DISCUSSION OF RESULTS:

The comparative analysis of the on-site monitoring data of all studies was conducted with respect to the predicted comfort bands by both Humphreys & Nicol formulated on the basis of Lucknow metereological data. On basis of Aulliciems a comfort band of 7 ºC width was considered as these houses utilised an adaptive informal lifestyle. The scrutiny showed that in summers the variable cases within all generic types of houses lay within the band with a difference of just 3.5°C within the closest and farthest cases. However in this season as per the afore-mentioned analysis, the city courtyard houses (Narhai house closest) generically performed better than the bungalows & mud houses. Furthermore in winters the bungalows as a type showed improved performances (Rachna house closest to desirable comfort temperature) while the city houses with larger courtyards achieved lower thermal performances & the mud houses were even worse. In monsoons generically the city courtyard houses (Narhai house followed by Jannat house) performed better than mud houses & even more so than bungalows.

On a finer analysis of the temperature data of variables within one type it was gathered that there was significant deviation within the thermal performance of one generic type meaning that in the same season one case within the same generic type performed best while another was one of the poorest amongst all cases. Notwithstanding the above, the most important inference was that within all cases the temperature variation was not great while the difference in the indoor relative humidity readings was even more minimal. In summers and winters the difference in maximas & minimas was less than 5°C while in monsoons the variation was limited to only 3°C. It was also observed that the bungalows recorded the lowest diurnal variations among all cases. Relative spot readings within the same house indicated a difference of up to 2°C in the temperatures. On close observations it was found that Narhai house- a core urban courtyard house recorded lowest indoor temperature in summers while the Rachna bungalow experienced higher internal temperatures in winters whereas in monsoons Narhai and Jannat courtyard houses noted best inside conditions. These outcomes also led to the understanding that all the


NARHAI HOUSE MONSOON TEMPRATURES
TEMPERATURE
DAYS
Tomax
Tomin
Tfimax
Tfimin
40
35
30
25
20
15
10
5
0
10.7.13
11.7.13
12.7.13
13.7.13
14.7.13
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19.7.13
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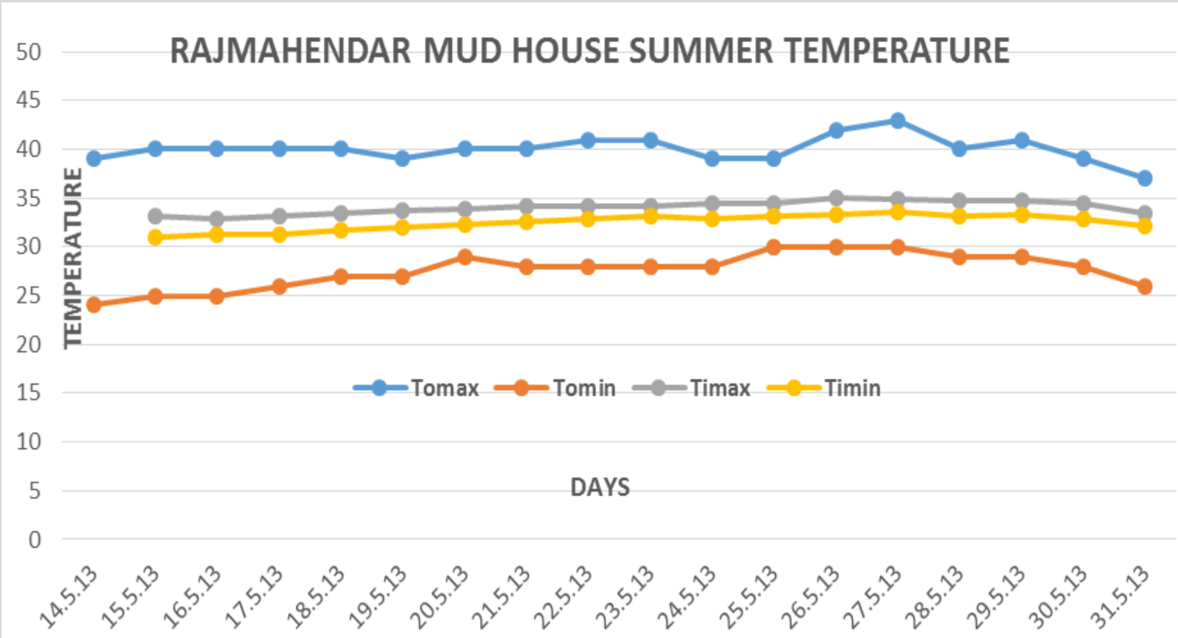
RAJMAHENDAR MUD HOUSE SUMMER TEMPERATURE
TEMPERATURE
DAYS
Tomax
Tomin
Timax
Timin
50
45
40
35
30
25
20
15
10
5
0
14.5.13
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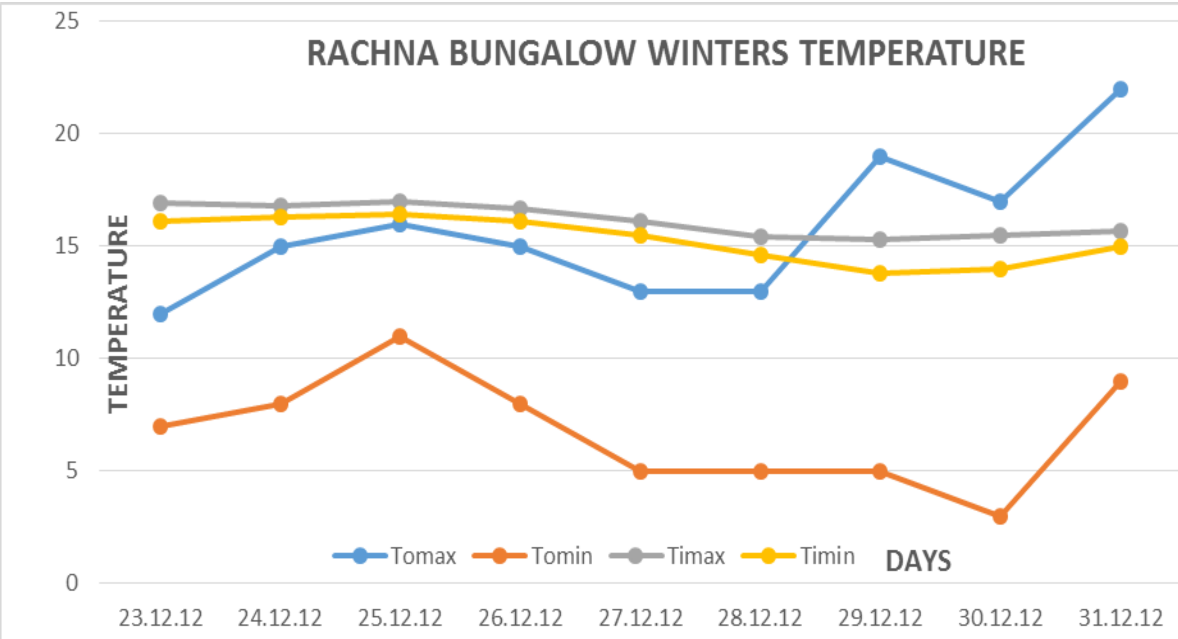
RACHNA BUNGALOW WINTERS TEMPERATURE
TEMPERATURE
DAYS
Tomax
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25
20
15
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23.12.12
24.12.12
25.12.12
26.12.12
27.12.12
28.12.12
29.12.12
30.12.12
31.12.12

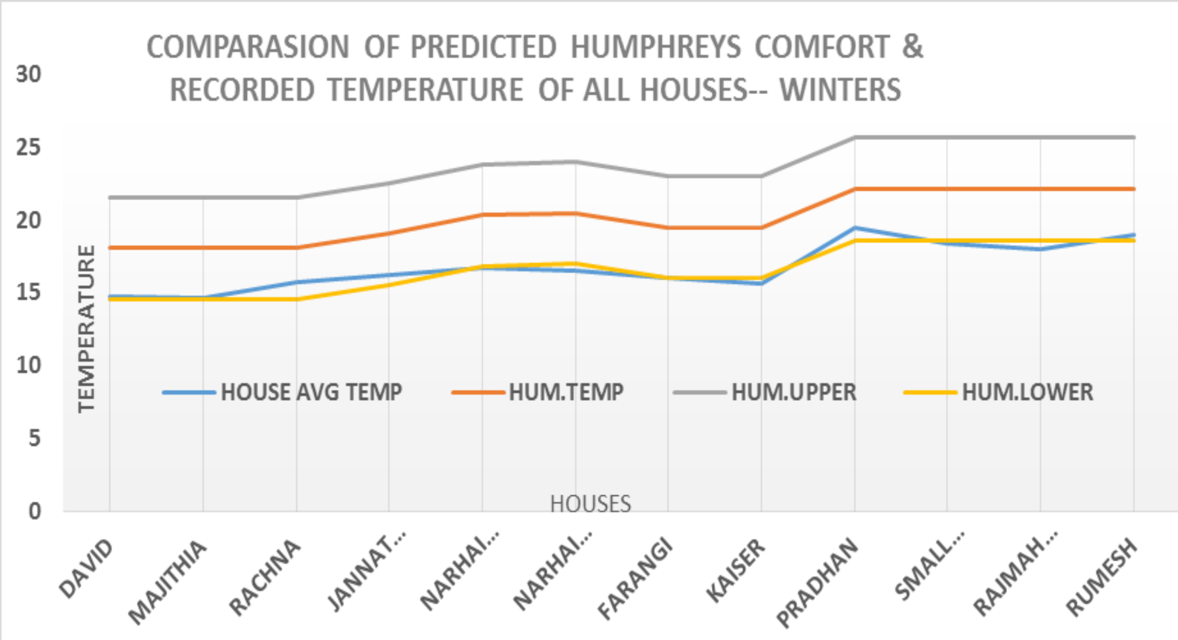
selected cases of vernacular houses were thermally comfortable although the superiority of one type over the other could not be distinctly established in any season. In fact it was realised that each house utilized a combined chemistry of varied strategies and sub-strategies for effective responses to varied seasons.

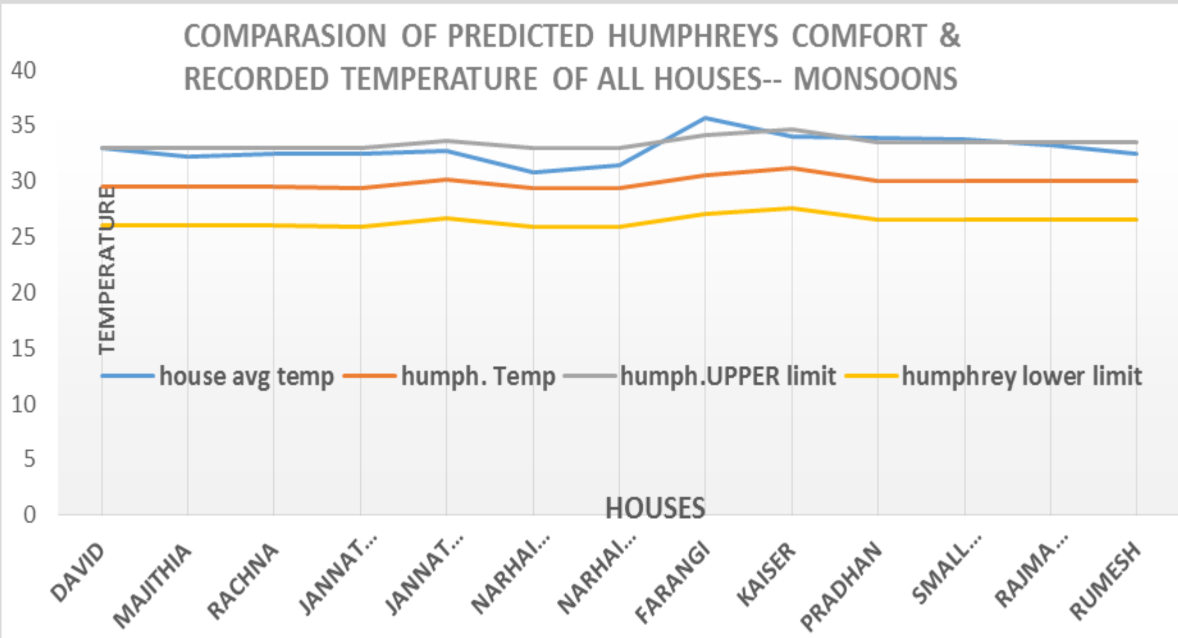
The Ecotect simulations for each case was calibrated on basis on existing data and the comparative assessment of their cooling, heating loads, monthly discomfort hours & temperature distribution was made. After which these models were also simulated with varying factors of orientation, material properties, and fenestration, shared walls, changed massing & varying shading systems. The implications of analysis by Ecotect revealed that the maximum heating loads were required by the Small Mud House while Rachna Bungalow and Narhai House needed minimum heating loads. Alternately maximum cooling loads were used by Pradhan House and minimum by Majithia, Narhai and Rajmahendar Houses. The living areas of all houses exhibited more constant hourly temperature profile than the other rooms. Variations in the simulation models also revealed the change in loads with modifications in upper floors, shared walls, orientation, fenestration, shading and materials that have been summarised in the coming paragraphs.

CONCLUSION

The most significant inference of the study was that all the generic vernacular house types of Lucknow were found to be thermally comfortable in the varying seasons of the region due to diverse multiple passive strategies adopted by them to counter the extremities of outdoor conditions. While the superiority of thermal performance of one generic type over the other could not be distinctly established in any season it was evident that the combined chemistry of varied strategies & sub-strategies were utilized by each case for effective thermal response to the existing climatic conditions of Lucknow. The architectural study of the selected cases within each generic type and across types revealed the passive strategies and sub-strategies utilised by the variants for effective response to prevailing climatic conditions. The core urban city courtyard houses employed siting amid narrow mutually shaded dense winding streets with minimal fragmented spaces whereas the bungalows comprised of siting in large open airy heaviliy foliaged sites. The mud houses on the other hand used a combination of the above with dense clusters amid large open sites. Furthermore the city houses had multiple shared walls with staggered massing of over floor to counteract heat gain & provide shade while the bungalows employed a minimised envelope with shaded verandahs and trees on periphery for the same. The mud houses on the other hand used partial shared walls and shading from adjoining large trees. Moreover the city and mud houses have used introverted courtyard plans with minimal outside fenestrations for preventing heat gain while bungalows have utilised large fenestrations opening into shaded verandahs and high ceilings with ventilators for enhancing convective cooling & ventilation. The use of high thermal capacity materials with high thermal lag in all the houses has contributed to constant temperatures all day and over the year.

It was also quantified by simulations of the selected cases that, the use of high thermal mass in building elements could improve the performance of the envelope to 70% but would prove detrimental without night purge ventilation validating the role of ventilation versus insulation. Furthermore it was observed that the strategy of orientation of vertical facades with respect to sun has been largely overrated in this region for structures below 3 stories. It contributed to a deviation of only 5 to 10% whereas the influence of effective mutual shading could improve the performance up to 30%. This study also substantiated that although solar radiation assumed maximum significance within the tropical Indian climate **the role of wind and air movement had to be taken into account for favourable thermal performance of built envelope**. Moreover Roof shading has shown to be extremely effective in this climate while effective massing improved the performance of lower floor up to 45%. Effective Shading of walls & fenestration have shown to reduce heating & cooling loads by 30% while presence of small courtyards has also indicated usefulness in all seasons. Verandahs as shading devices have exhibited significance & have a larger role to play built forms at Lucknow to articulate facades provide shading & prevent thermal shock in extreme outdoor conditions. The recommended Fenestration proportions have


COMPARASION OF PREDICTED HUMPHREYS COMFORT & RECORDED TEMPERATURE OF ALL HOUSES-- WINTERS
TEMPERATURE
HOUSES
HOUSE AVG TEMP
HUM.TEMP
HUM.UPPER
HUM.LOWER
0
5
10
15
20
25
30
DAVID
MAJITHIA
RACHNA
JANNAT...
NARHAI...
NARHAI...
FARANGI
KAISER
PRADHAN
SMALL...
RAJMAH...
RUMESH


COMPARASION OF PREDICTED HUMPHREYS COMFORT & RECORDED TEMPERATURE OF ALL HOUSES-- MONSOONS
TEMPERATURE
HOUSES
house avg temp
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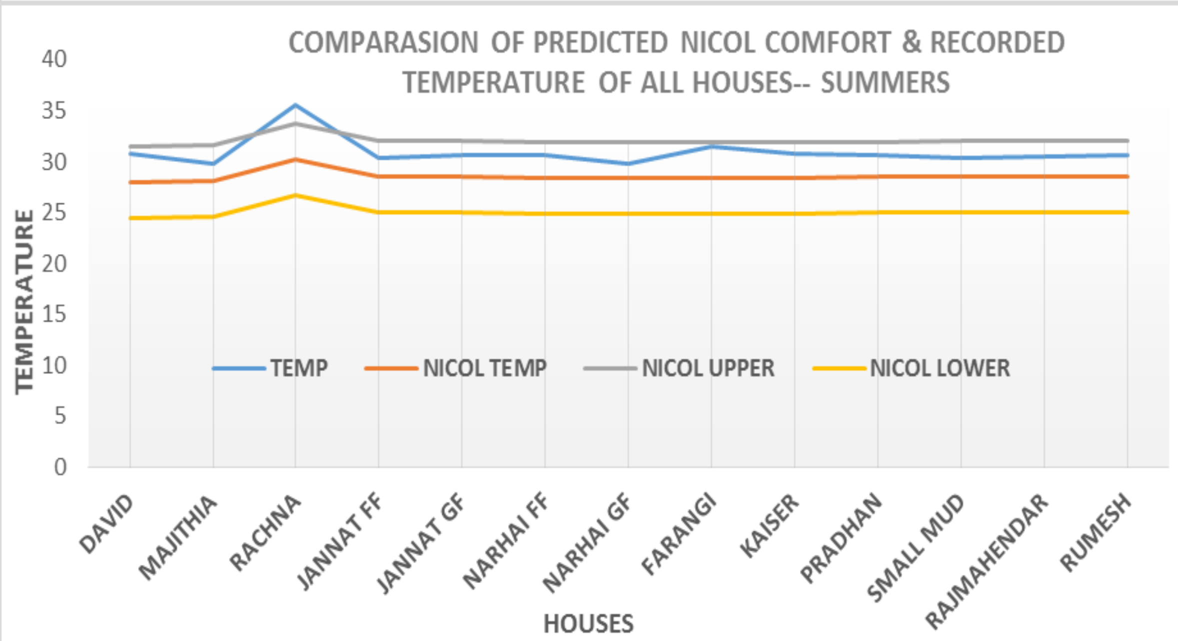
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seen to work more effectively in combination of ventilators & doors reducing loads by up to 32%. The study also showed that a non-parochial view of materials was to be required and their role in a combined assembly system should be assessed.

Furthermore Simulative modelling techniques have made visualisation and subsequent design much easier but **the study resolves that the unrestrained use of simulation software's without an assessment of real conditions are a cause of concern** because despite multiple configurations **they underestimate the role of wind and air movement.** Furthermore in simulative models **insufficient credence is given to adaptations** due to physical actions in actual environments leading in inaccurate results. Especially in the case of naturally ventilated buildings in the Indian climate their role has to be examined more closely and thus selected with extreme care that would need to be calibrated with actual on-site data. India is fast becoming a global phenomenon as a result of which **modern living comparatively has become more inflexible** with minimal space reallocation even in the extreme conditions. In an age of fast depleting resources and power crisis learning from the adaptive and flexibility principles of the vernacular makes sense to restrict reliance on active systems of cooling and heating loads

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Assessing Sustainable Retrofit of the old Dwellings Stock in Brussels Capital Region

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ABSTRACT

In the framework of the research project "B³RetroTool", a typology of existing dwellings, built before 1945, has been made, based on a literature review of main steps of the urban and building development of Brussels area. This old part of the Brussels dwellings stock has been chosen because it represents 60% of the dwelling stock but moreover, it gives to Brussels its identity, its architectural and its historical legacy.

This contribution presents the methodology to identify typology, to structure a representative database of existing dwellings stock (with spatial distribution in Brussels area) and to define criteria to assess retrofitting strategies for each dwelling type in order to enhance heritage value and to combine it with relevant energy and environmental performances. The originality of this research is to consider energy, environmental and heritage aspects in a non-compartmentalized and complementary way, in order to help designers to reach their objective of a greater sustainability.

INTRODUCTION

The dwellings stock built before 1940 in Brussels has a great heritage value for Brussels Capitale. It also represents 60% of built areas and is responsible for 62% of the region's energy consumption. This fact has prompted Brussels to invest in strong support for reducing energy consumption in buildings through systems of subsidies. These include subsidies for insulation, replacement of windows, boilers ... So as to target the strategic policy actions in terms of reduction; the Brussels Capital Region has also invested in targeted studies on the state of the existing building stock and opportunities for improvement. All of these studies, mainly based on statistical studies have rarely considered both the heritage and historic value of the buildings and the improvement potential related to buildings components and design principles.

The research's objective is to achieve important improvements in the energy performance of existing Brussels dwellings stock while preserving heritage value and reducing environmental impact.

The research focuses only on the dwelling stock built before 1940 for three main reasons. First, this is the largest share of the Brussels dwellings stock. Secondly the differents types of dwelling could easely be identified.Thirdly, this dwellings stock requires urgent improvements in terms of energy performance and inhabitancy. It should also be noted that dwelling demand is very strong in Brussels. So the retrofit of this dwelling stock could meet this demand by densifying some dwelling types.

This contribution presents identification of dwelling typology built before 1940, proposition of retrofitting scenarios and definition of energy, environmental and heritage value criteria in order to enhance heritage value of the Brussels dwellings stock and to combine it with relevant energy and environmental performances but also suitable materials and systems. It describes in details the methodology used for identification, repartition and spatial distribution of dwelling typology. Retrofitting scenarios and assessment criteria are subsequently presented.

This research is still ongoing and the results of scenarios assessment are not yet known. The overall results: dwelling typology, its repartion and spatial distribution as well as improvement scenarios and their assessment through case studies will be incorporated into a pre-assessment tool to retrofit the dwellings in an integrated multi-criteria and multi-scale approach.

HISTORICAL RESEARCH: URBAN DEVELOPMENT OF BRUSSELS, FROM THE 10TH TO 20TH CENTURY

The first step of the research was to study the historical processes [1, 2, 3, 12] that have influenced the development of the city of Brussels and the Brussels-Capital Region in order to understand the urban characteristics and specificities but also to know the origin of the development of certain types of city blocks and dwellings. Brussels-Capital Region, as it is today, was formed mainly during the last two centuries. But some key elements are older. They are, as example, the topographic or hydrographic elements that were at the origin of the spatial and social differentiation between high side (east and more aristocratic) and low side (western, most popular and industrial) of the city. This spatial and social differentiation is still present today, although less pronounced than originally. It is also the work of fortifications that gave the city center of Brussels, a specific and still visible form. It is also major infrastructure projects such as the creation of the boulevards on the second enclosure, the creation of Willebroeck and Brussels-Charleroi canals, the creation of large avenues, the creation of the North-South Train Junction... All those elements must still be reconsidered in strategies for urban renewal of the region through different scales: neighbourhoods, city blocks and buildings.

This historical research focuses mainly on morphology, demography, urban planning, architecture and types of dwelling.

DEFINITION OF DWELLING TYPOLOGY

The study of the dwelling typology before 1945 has been established from the late 17th century for two main reasons. First, dwellings built before 1700 are mainly wooden buildings. In 1695, those wooden buildings were almost destroyed (as the entire city) by the French bombing. The Brussels rebuilding was made with bricks and stones, on the track of the old wooden dwellings. Secondly building permits and the various regulations standardizing construction spread in the 18th century.

Dwelling types were defined according to the historical research of Brussels urban development but also to the changes in lifestyle of Brussels citizen as well as changes in construction methods and materials used. Three main periods of urban development have been identified.

From 1700 to 1890: urban development of Brussels. Period characterized by the first great works of urbanization and development of the future Belgian capital city (1830).

From 1890 to 1914: transition period. Period characterized by hesitation between the nostalgia for the past and the desire for modernity and a new architectural trend, the “Art Nouveau” launched by Victor Horta, with the construction of Hotel Tassel in 1893.

From 1920 to 1945: modern period. Period characterized by a strong demand of housing but also new ways of thinking architecture and urban development.

Regarding the types of dwelling, the research distinguished two key periods:

From 1700 to 1914. Period characterized by a predominance of individual housing (modest, bourgeois and aristocratic), whose spatial organization will be based on the spatial organization of the “maison bourgeoise”;

From 1920 to 1940. Period characterized by the emergence of new types of dwellings, mainly worker house in the garden cities and apartment building but also new constructive processes and new materials, especially concrete.

Based on archival and/or historical documents, each type of dwelling has been studied according to the methodology including a general description of the type (description of dwelling situation, spatial organization, internal circulation and stair case, building systems and materials, roof, façades and building materials), a description of the main characteristics (relation with public space, size of the plot, size of the building, volume, number of floors, presence of annexe, height and width of the main façade…) and description of type variations if they exist.

Dwelling typology from 1700 to 1914 [4, 5, 11, 14]

The single family row house is the most common form of dwelling in Brussels until 1914. For this period, there are three main types of dwelling: the “maison bourgeoise”, the modest or worker house and the “hôtel de maître”. These types are the evolution of the Brussels wooden row house and are thus characterized by the same spatial organization, construction principles and materials that can be presented through the “maison bourgeoise”:

Spatial organization. It reflects the lifestyle of the bourgeoisie in the 19th century and it is organized in three modes: reception, family spaces and services or domestic spaces. Internal spaces are divided into two parts: a main part including the reception and living spaces and a secondary part, narrower, including services, stairs and corridors. The plan is organized with a succession of two or three rooms with a depth of 4 to 4.5 meters. Reception and living spaces have high ceilings, large width and are largely lit.

Construction system, principles and materials. The construction system is mainly governed by the rules of protection against urban fire. It is based on the constructive system of the Brussels wooden row house. Party walls are made of brick locally sourced and are not structural. The wooden floors are perpendicular to the street facades and partition walls. The wooden beams are spaced between 35 and 40 cm. The thickness of the bearing brick walls is also codified by the regulations of buildings to ensure stability. It varies between 28 cm and 48 cm depending on the type and height of walls. Recovery of floors charges and load-bearing walls is ensured by a combination of discharge vaults and metal lintels scattered throughout the façade and load-bearing walls. Only the structure of the roof is based on party walls, wooden beams ranging from wall to wall. The floors of the ground floor are partly made of hard materials. They are tiled or covered with marble. Floors of the upper levels are in wood. The ground cellars are usually performed in clay.
The two façades are narrow (6 m) and high (12 to 18m) but there is however a big difference in composition between the two façades. Back cover: brick facade, sober and coated. Only a few metal lintels and sills are apparent. Main façade composition depends on different styles: neoclassical, eclectic,... Materials used are brick, natural stone and oak for window frames. The level of the street façade decoration shows the social level of inhabitants.

Dwelling type variations. The type “maison bourgeoise” could be divided into three variations according the construction date: “maison bourgeoise” built before 1800, “neoclassical maison bourgeoise” and “maison bourgeoise bel étage”. Those three variations have the same spatial organization and same internal plan but show variations at the level of groundfloor and stairs installation.

The same construction systems and materials are found in the modest house and in the “hotel de maître”. Only the location, the size of the plot, the width of the main façade, the surface area, number of floors, the appearance of the street façade and interior finishes are different. Modest or worker row houses were mostly located in the popular and industrial districts. Maisons bourgeoises were located in residential districts of the pentagon, mainly in the top of the city. Hôtels de maître built for the upper bourgeoisie and aristocracy, after 1830, were located along large avenues and in some districts extensions. In addition to these three types, there are also houses with shop and apartment houses that show a lot of similarities with the “maison bourgeoise”. Those types of dwelling were located on the corner plots and near train stations and infrastructure.

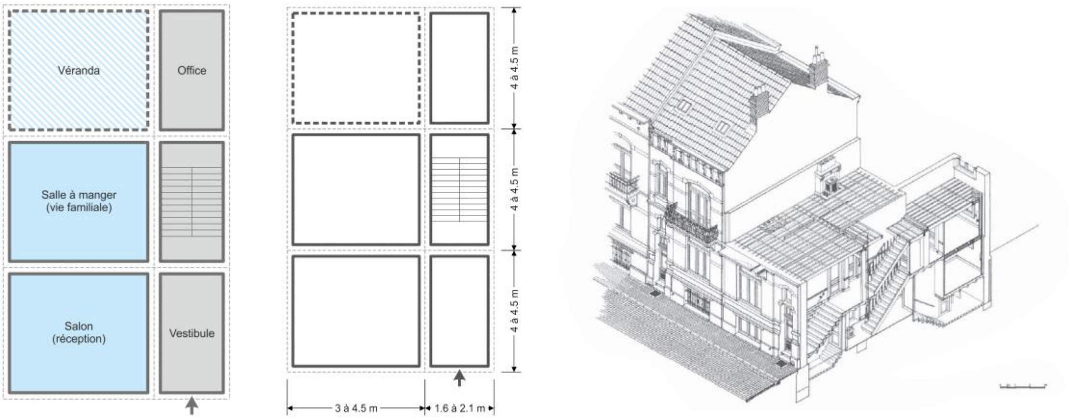

Figure 1 Left: Spatial organization - Center: main dimensions - Right: construction principles of the “maison bourgeoise”

Dwelling typology from 1920 to 1940 [6,7,8, 14] **.**

The beginning of World War I, in 1914, traditionally marks the end of a period both in Western Europe in Brussels. Mentalities as well techniques evolve significantly: the car is spreading, domesticity disappears, the role and place of women change. Changes also appear in the ways of life of the bourgeoisie and the working population. These changes have an impact on the spatial organization of dwellings, on the urban development of Brussels and on the types and styles of dwellings whether individual row house remains predominant. Garden cities are built for the workers at the extremities of the city. By 1930, after the financial crisis of 1929, apartment buildings for middle class - back in town - are growing in Brussels. For this period, we can distinguish three types of dwelling: evolution of the “maison bourgeoise”, worker row house in garden-city and apartment building (social and standard). If the evolution of the “maison bourgeoise” still presents many spatial similarities with the “maison bourgeoise” built before 1914, the two other types show a new spatial organization [figure 2]. All three types also were built with new construction systems, principles and new materials, especially concrete.

Figure 2 Left: Plan of garden-city row house (1922) – Right: plan of standard apartement building (1930)

Case studies of dwelling types

For each type of dwelling, a case study sufficiently representative has been searched. With this objective, various Brussels databases and information sources [15] have been consulted and various architects working with old buildings and dwellings have also been contacted. Each case study will be analysed based on original plans, sections and detailed quantity survey.

Figure 3 Pictures of “neoclassical maison bourgeoise”, “maison bourgeoise bel étage”, “hotel de maître”, apartement house, evolution of maison bourgeoise 1, evolution of maison bourgeoise 2, standart apartement building and social apartement building.

Building stock analysis – Dwelling type repartition

Based on the description of each dwelling type, a simplified characterization has been proposed to fit the data given in the Brussels cadastral matrix (©Administration Generale de la documentation patrimoniale) and to associate each lot to one type. As we can see in the figure 4, the characterization is limited to three factors: date of construction, floor area, number of dwellings per building. There is a total of 159825 buildings and 498819 dwellings registered in the Brussels cadastral matrix.

Type	TYPES BATIMENT B³-RetroTool	avant 1850	1850-1874	1875-1899	1900-1918	1919-1930	1931-1945	Surf utile / Bat	Nb log / Bat	Surf/Log
0	Non applicable								0 ou 999	< 8
1a	Maison bourgeoise d'avant 1850							120-350		
1b	Maison bourgeoise type leopoldien (néoclassique)							120-350		
2a	Maison bourgeoise avec bel étage (1 logement)							120-350	= 1	
2b	Maison bourgeoise avec bel étage (> 1 logement)							120-350	> 1	
3a	Hotel de maître ou hôtel particulier							351-1000	<= 4	
3b	Maison de rapport							351-1000	> 4	
4a	Maison modeste d'avant 1919							25-119		
4b	Maison modeste après 1918 (dont cité-jardin)							25-119		
5a	Maison bourgeoise - Evolution (1 logement)							120-350	= 1	
5b	Maison bourgeoise - Evolution (> 1 logement)							120-350	> 1	
6	Immeuble à appartement							>350		
7	Après 1945									

Figure 4 Characterization of dwellings types

The figure 5 confirms that more than 60% of the buildings were built before 1945. This analysis shows that "maison bourgoise” (type 2 in the figure) outnumbers all other types and that many post-war buildings are apartments.

Then, with ArcGIS software, the resulting database can be used to analyse spatial distribution of each type. The left map [figure 6] shows that type “maison bourgeoise” was mainly built close beyond the first encloser. The right map [figure 6] shows that after 1918 the type “evolution of maison bourgeoise” (type 5) was built further out the centre, beyond the second encloser.

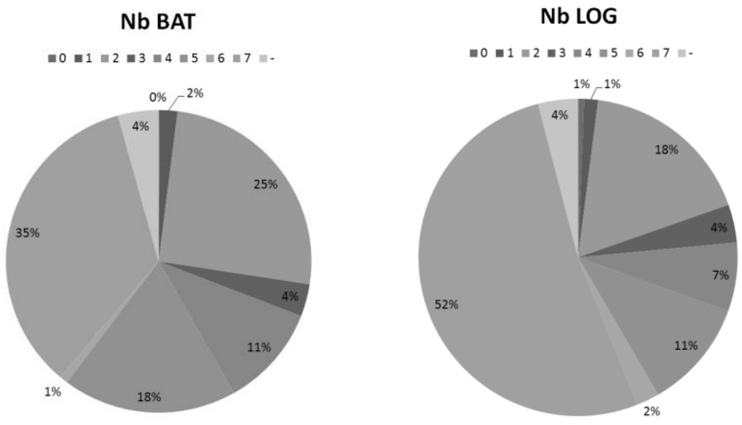

Figure 5 Repartition of dwellings types by building (left) and by dwelling (right)

Figure 6 Spatial distribution of dwellings types: left: “maison bourgeoise” built before 1914 and right: “evolution of maison bourgeoise” built between 1920 and 1930

ASSESSMENT OF POTENTIAL IMPROVEMENTS OF DWELLINGS STOCK

Based on the description of each dwelling type, various scenarios of retrofitting were proposed. They focused mainly on improving the energy performance of each dwelling type but also on creating opportunities for dwelling densification, function diversity and inhabitancy improvement. Scenarios proposed for each dwelling type will then be applied to the specific case study and assessed according to three criterias (heritage value, energy and environmental impact) and compared with the initial situation.

Climatic data of Brussels Capitale Region

The reference Belgian external climate is a relatively cold, humid and rainy temperate climate. The data presented below, were measured by the Belgian Weather Royal Institute in Uccle (Longitude: 4.36°E, Latitude: 50.80°N; Altitude 100 m): average temperature (9.9°C), average relative humidity of the air (80%), average wind speed and orientation (3.6 m/s, south-west), average global solar radiation (108 W/m² with min:0 - max 889) and average precipitation (930 mm per year).

Assessment criteria

Each assessment criteria - energy, heritage value and environmental impact - contains a series of indicators presented in the table on the next page.

Table 1. Assessment criteria

Energy	Heritage value	Environmental Impact
Transmission coefficient [U] of the walls and frame	Building quality	LCA of building materials (GWP, AP, POCP)
Efficiency of the technical systems	Coherence quality	Amout and type of waste produced
Overall performance of the dwelling: - Average U - Level E	Preservation quality	LCA of technical systems (GWP, AP, POCP)
Total grey energy (NRE, RE)	Resilience quality	

Potential improvements of dwellings stock – retrofitting scenarios [9, 14, 15]

Various scenarios were proposed with the objective to improve significantly the energy performance of the dwellings. Those scenarios focused first on the envelope and then on the technical services. The envelope retrofitting scenarios were defined based on a trend analysis performed on the renovation of housing awarded at Exemplary Buildings initiated by Brussels Environment. They are proposed by phases, knowing that today, only few Brussels owners can finance all of the retrofitting works in one phase. The retrofitting steps are proposed in a hierarchical manner, taking into account the state of the dwelling, the influence on the energy performance and the extent of work required. As an example, the envelope retrofitting scenarios for the “maison bourgeoise” are the following:

1. *Roof insulation:* the insulation could be done from inside or outside. Insulation from inside preserves the structure and the covering. Insulation from outside requires a new covering and sometimes a new structure. Insulation from outside also requires a special attention to specific elements and ornaments and could be linked with integration of renewable energy system
2. *Roof insulation + Floor slab insulation*
   In case of “maison bourgeoise bel étage” with a raised ground floor and cellars naturally lit, the floor slab could be insulated from inside. In case of “neoclassical maison bourgeoise” with a ground floor at street level and cellars without natural light, the floor between ground floor and cellars could be insulated (cellars side).
3. *Roof insulation + Floor slab insulation + Frame replacement (back cover façade)*
   In many dwelling, frames are still equipped with single glazing. Those should be replaced by double or triple glazing frames taking into account the possible installation of solar protection (orientation) and increase of the airtightness.
4. *Roof insulation + Floor slab insulation + Frame replacement (back cover façade) + back cover façade insulation*
   Back cover façade could easely be insulated from outside. The most common technique is the coating on EPS insulation but wood-based materials will also be assessed.
5. *Roof insulation + Floor slab insulation + Frame replacement (back cover façade) + back cover façade insulation + Glazing and/or frame replacement (main façade)*
   The main façade being highly ornamented and the frame strong, the replacement of the frame and/or glazing therefore requires a detailed study. Several solutions can be considered: preservation of existing chassis and replacing single glazing by double glazing or replacement of all
6. *Roof insulation + Floor slab insulation + Frame replacement (back cover façade) + Back cover façade insulation + Glazing and/or frame replacement (main façade) + Main façade insulation*
   The main façade being highly ornamented, insulation from outside is really not possible. Insulation by inside means to pay attention to thermal bridges between façades and wooden beams and requires a detailed study [10].

The technical services retrofitting scenarios are proposed taking into account the existing technical services and the possible densification of the dwelling. The scenarios propose improvement strategies for existing techniques but also for integration of ventilation systems, renewable energy systems (solar thermal and PV), rainwater infiltration systems and acoustic insulation (in case of dwelling densification). They presented, for each dwelling type, solutions for ducts implantation.

The densification retrofitting scenarios analyse the possible way to increase the number of dwelling, especially into the “maison bourgeoise” characterized by a very large surface area available (up to 400 m²). Some scenarios propose a diversity of functions by integrating professional spaces into the dwelling.

CONCLUSION

The paper presents the methodology used to analyse and caracterise the brussels existing dwellings stock. The data will be used to develop a tool to help improving global performance of this urban area. A definition of dwelling typology was detailed and each building from cadastrial database was associated with one type. Using ArcGIS tool, a map of each type can be drawn. For each type, refurbishment scenarios were proposed, as well as three set of criteria to assess energetic, environmental and heritage value in parallel. Developping tool should thus allow assessing simultaneously these three aspects and their interactions. This methodology can be applied in other contexts to provide any user with data at different scales, from the building to the entire city, helping to take sustainable decisions.

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Passive House Elements of Traditional Bosnian Town House: Towards Contemporary Passive House in Bosnian Context

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ASTRACT

Bosnia-Herzegovina, a country going through the process of development, has many challenges to overcome in order to achieve satisfactory energy efficiency of its built structures. In the last couple of years, activities to increase energy efficiency of residential buildings have gained momentum in order to align with the European Union energy efficiency legislature. The majority of those activities consist of building stock refurbishment by simply adding thermal insulation onto existing architecture.

Considering the climatic conditions, of warm summers and cold winters, decreasing heat loss is important aspect in striving to achieve thermal comfort and energy efficiency of the buildings in Bosnia-Herzegovina. Other means to achieving thermal comfort could be found in Bosnian vernacular architecture, especially when considering thermal comfort in the summertime. Vernacular architecture offers original passive architectural design solutions that are waiting to be utilized in contemporary design.

Although comprehensive research on many of the aspects of the traditional Bosnian town house have been done in the past, its passive-design elements have not been recognized as such nor systematically studied. This paper aims to introduce passive architectural elements, passive cooling and ventilation techniques to a broader public.

Excellent house performance could potentially be achieved by the integration of the vernacular design traditions, of the Bosnian town house, into contemporary passive-house designs.

Thermal performance of a traditional Bosnian town house is tested through computer aided simulations and site measurements. The results of the study should provide convincing arguments, for the local architects and policy makers, to steer the often misguided and overly provisional trends in house designs, to the sustainable path.

INTRODUCTION

In efforts to achieve sustainability it is up to each country to select solutions suitable for their specific conditions and environment. In Bosnia-Herzegovina, where privately owned, individual housing represents a popular lodging solution, finding a sustainable solution for this particular architectural category is already overdue. Some of the housing that was already built inadequately is now going through refurbishment process of adding thermal insulation, to increase thermal performance. Domestic

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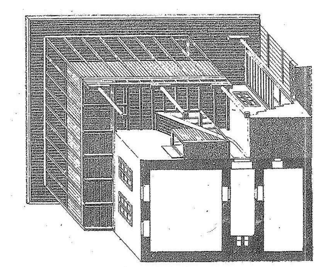
households take up 52% of final consumption of energy (ESSBIH 2008) and in general buildings mainly have a poor thermal insulation which causes energy loses of up 30% (CPU 2010).

The study of vernacular housing solutions in a particular environment is an excellent venue for revealing design solutions that can be replicated in the same environment but in a contemporary context. This is particularly suited to passive architecture, which makes use of its surrounding natural environment as much as possible. Beside the natural environment, a significant part of passive housing efficiency is based on the occupants' behaviour. One can argue that vernacular architecture is the original passive architecture. Making the contemporary passive architecture possible are several inseparable elements: the natural environment, the lifestyle and the architecture design itself. This paper aims to explore specific passive-architecture elements of a traditional town house in Sarajevo, Bosnia-Herzegovina through the case study of *Svrzo's House* in Sarajevo.

2. THE TRADITIONAL BOSNIAN TOWN HOUSE - BACKGROUND

The house chosen for the study is a two-storey house with elaborate ground and upper floor plans. It is known as "Svrzo's house" and is located on the hills of the old part of the town overlooking the city of Sarajevo. It dates back to the 18th century when it was owned by a wealthy local family. It was later donated to Sarajevo City Museum to be converted into a museum itself during the 20th century. This house is particularly suitable for study since it contains a variety of the typical architectural design elements of Bosnian town house and is kept close to its original state.

a)



b)

Figure 1 a)Svrzo's house (2014), view on the front courtyard and open terrace space - *divanhana* on the upper floor clearly distinguished in wood works (Bajramovic, 2014) b) Typical configuration of Bosnian town house, cantilever architecture: ground floor masonry, and upper floor's timber framework with brick infill (Grabrijan& Neidhardt 1957)

Figure 2 The Ground and Upper Floor plans of traditional Bosnian town house: Svrzo's House in Sarajevo, Bosnia-Herzegovina, renovated to original form and turned into a museum.(Grabrijan& Neidhardt 1957, graphic editing by author)

2.1. Lifestyle and occupants' behaviour

Traditionally, parts of the house were classified according to their functions, into four groups: habitation, recreation, domestic activities, circulation (Grabrijan& Neidhardt 1957), but the rooms themselves were used very flexibly. The furniture is also flexible, there is the sofa encircling the room on 3 sides and *Musandra* (a walk in closet consisting of a stove, a shower space and a closet), while the rest of the space of the room is free to be used in different ways.

The number and use of the rooms is set according to the needs of the family, flexibility being the key. The same room can be used as living - dinning room that transforms into bedroom during the night, other rooms can be children, study or guest rooms. The house is typically a two-story where the ground floor is used as winter quarters, and the upper floor is used as summer quarter. Depending on the house configuration the upper floor is sometime used additionally for winter quarters (Grabrijan& Neidhardt 1957). Such use of the house is a result of a the climate, hot summers and cold winters. Winter quarters are connected to the outside through *verandah* (Figure2), and summer quarters open to outside through *divanhana* (open terrace space – Figure 1&2). Common use of the house by its tenants could be categorized in the following way: 1. Summer and winter use and 2. Private and semi-private use. Front part of the house, adjacent to the main gate courtyard, is considered semi-private, since the guests are greeted there, but second part of the house is completely private.

Several unique architectural elements allow for comfortable summer and winter habitation. The occupants' behavior is adjusted based on the season.

2.2. Passive-architecture features of the house

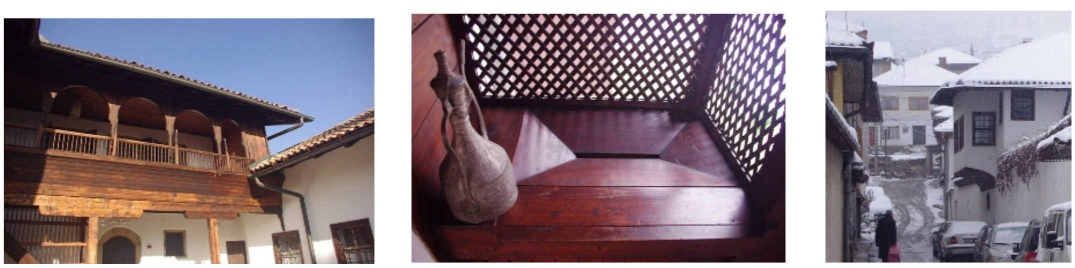


Figure 3 a) Divanhana – open-air terrace space, under deep eaves b)mushebak , c)doksat (photos by author)

Divanhana,(Figure 3.a) an open-air terrace on the first floor settled under deep eaves which provides a comfortable place to reside in hot summer days. All of the rooms adjacent to it have a direct access through massive wooden doors, and with windows looking onto it. Divanhana, together with narrow open hallway, connects pavilions of the house and enhances the airflow throughout the first floor of the house. It is accessible from the ground floor courtyard directly by stairs allowing for quick access to the rest of the house. With its built-in bench and attractive views it is mainly used for recreational activities such as reading, talking, enjoying the scenery, as an outside summer living room. It is even used even as sleeping space in warm summer nights (Grabrijan& Neidhardt 1957).

Mushebak crossing wood lattices in the windows providing enormously valued privacy. It enables cross ventilation of divanhana and hallways (Figure 3.b)

Doksat, a prism with window jutting out in the height of the upper floor of the house, overhanging the street (Figure 3. c). It is a standard architectural element that appears on all typical town houses. Since it provides 180 degree view, it is primarily used to overlook over the surrounding neighbourhood. It additionally plays an important role in house's cross ventilation; windows on all 3 sides which gives room for creating draft and ventilating the room more efficiently (Grabrijan& Neidhardt 1957).

The Garden and courtyards (Figure1&2) are places where one enjoys nature, where decorative and edible plants were planted and taken care of. Summer quarters of the house are oriented onto the garden, which increases the cooling off effect in the hot summer days.

The construction of the house is favourable in terms of thermal mass. The ground floor consists of massive walls, made out of unbaked brick or stone, while the Upper floor consists of wood frame filled in with unbaked brick. The timber frame is resting on the masonry wall. Ceilings are supported by the wood frames and the roof is a heavy wood construction protected by roof tiles.

3. PASSIVE COOLING, VENTILATION, AND HEATING FEATURES

A traditional Bosnian town house (further in the text referred as a TBT house) is, among the locals, recognized as comfortable dwelling in the summer, while at the same time having an adequate thermal mass to sustain the heat in winter months. This study aims to test those qualities on one of the TBT house’s pavilions, which is a representative of typical volumes, materials, and layout.

3.1 Climate conditions

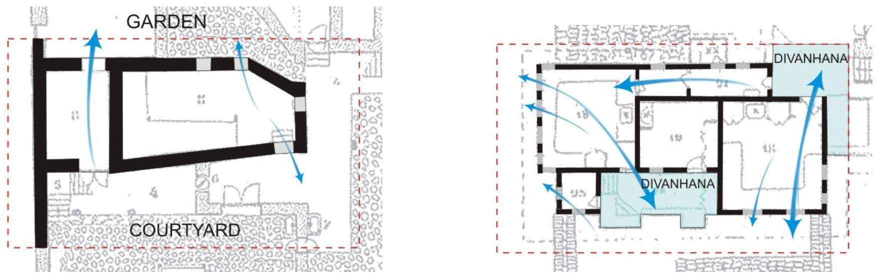
According to The Köppen Climate Classification the subtype for Sarajevo’s climate is "Dfb" (Warm Summer Continental Climate) or a medium continental climate with average winter temperatures of -1,3°C in January, and average summer temperature of 19,1°C in July. The average annual temperature is 9,5°C. The coldest month is January with the lowest recorded temperature of -26.1°C and the highest in July with 37.2°C (Weather Base 2014).

Summertime temperatures fluctuate drastically during the day where the average temperature difference between the early morning, afternoon, and evening can reach up to 10 to 15°C, with even more drastic differences between maximum and minimum temperatures. On average winter temperatures are fairly steady throughout the day, with slight decrease during the night, but with drastic maximum and minimum temperature differences across days (FHMI 2013). Humidity is also changing during the day, going from high in the morning (up to 80% yearly average in the morning), going down to 50% around midday and again getting higher in the evening hours. Prevailing winds are a result of complex geographical features, so there is a huge variety of wind directions and speeds. Prevailing directions are ESE and WNW. Dominant winds are SSW and ESE (FHMI 2013).

Although humidity rises during the night, these kind of climate conditions allow for effective night-time cooling because of the larg drop in temperature during the night. The traditional lifestyle comprises night-time cooling as a part of the daily routine in summer period. The prevailing wind directions suggest that the orientation of the house openings towards South and West is indeed favourable for natural ventilation. The selected TBT house has the optimal South and West facing openings.

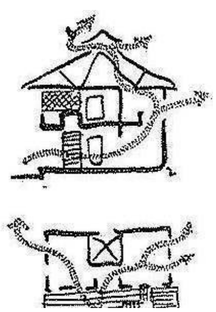
3.2. Cross-ventilation and vertical ventilation

In addition to acting as an outdoor living room in the hot summer days, aforementioned *divanhana* settled under the deep eaves, is a structure that represents a buffer zone, “a layer of air between the hot outer and cool inner spaces which gives rise to air circulation. The rooms behind the *divanhana* are connected to it by windows and doors and open into the side facades so that the ventilation around the corners is also possible”(Grabrijan& Neidhardt 1957)



a) b)

Figure 4. a).: GROUND FLOOR: Cross ventilation through the ground floor openings enabled by the openings' positioning and the difference between the interior temperature and exterior temperature of the courtyard and the garden. B.: UPPER FLOOR: Openings on the both sides of the rooms allow for cross ventilation. *Divanhana* plays an important role in the summer months, creating a buffer zone between outside and inside spaces. (Grabrijan& Neidhardt 1957, graphic editing by author)



The rooms that are placed in the central parts of the house, with no horizontal ventilation possible, are ventilated vertically through other rooms and the opening in the roof, as shown in the sketch (Figure 3.).It is clear why the house has been given an attribute of an "airy house" (Grabrijan& Neidhardt 1957) since it is ventilated in both the horizontal and vertical direction.

Figure 5. The airy house, an archetype layout and section of BTB house (Grabrijan& Neidhardt 1957)

3.3. Indoor thermal comfort – A computer simulation analysis

The thermal comfort of the TBT house was examined Using SolarDesigner simulation software (validation of software demonstrated in the article done by authors; see references: Kodama&Takemasa 1991). The pavilion of the house chosen for the computer simulation, represents a typical two-storey architecture of the area. The Ground floor is constructed through massive stone masonry, while the lighter Upper floor is constructed using the *bondruk system* – a timber framework with unbaked clay brick infill. The performance of the house pavilion Ground floor and Upper floor volumes (Figure 4. a&b) were examined according to different simulation scenarios: summer daytime and nighttime ventilation scenario, and winter *all day closed* mode ventilation scenario. Simulation was conducted for three consecutive days, in winter time, as well as the summertime. *Day 1* is considers as sunny with bright skies, *day 2* as partly cloudy and *day 3* as cloudy. The temperature values represent the maximum and minimum amplitudes recorded in July and January (consecutively the warmest and coldest month of the year).

3.3.1. Summertime ventilation and passive cooling effects

The TBT house, with ample thermal mass, is expected to benefit from the passive nighttime cooling effect in the summer. The computer simulation tested this on the Ground and Upper floor quarters (Figure 4 a&b). Room air fluctuation during July, the warmest month in this climate, is shown in Figure 7. There are noticeable differences between the Ground floor, and the Upper floor air temperature fluctuation. Traditionally utilized the most in the summertime, the Upper floor quarters, if kept closed all day, can provide a fairly steady temperature throughout the day. At this time of the year nighttime ventilation is the optimal ventilation mode. The optimal passive cooling effects are attained in the nighttime ventilation mode from 7 am to 9pm, (Shown in Figure 4) with indoor temperatures dropping up to 15°C, and which allowing the interiors to stay significantly cooler than the outside temperature. Similarly, summer nighttime ventilation on the Ground floor is the optimal ventilation mode, with temperature values going from 12°C up to21°C in the interior spaces. All day closed mode is providing good thermal comfort, with steady temperatures up to just 19-21°C even when the outside temperatures are around 34°C.

ventilation mode	day (8-18)	night(18-8)
daytime ventilation	30 times/h	2 times/h
nighttime ventilation	2 times/h	30 times/h
all day open	30 times/h	30 times/h
all day closed	2 times/h	2 times/h

Table 1 Ventilation modes (room air changes per hour)

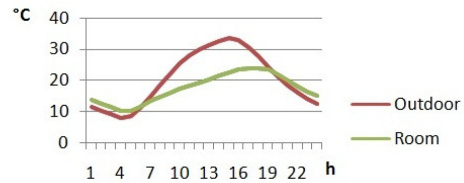
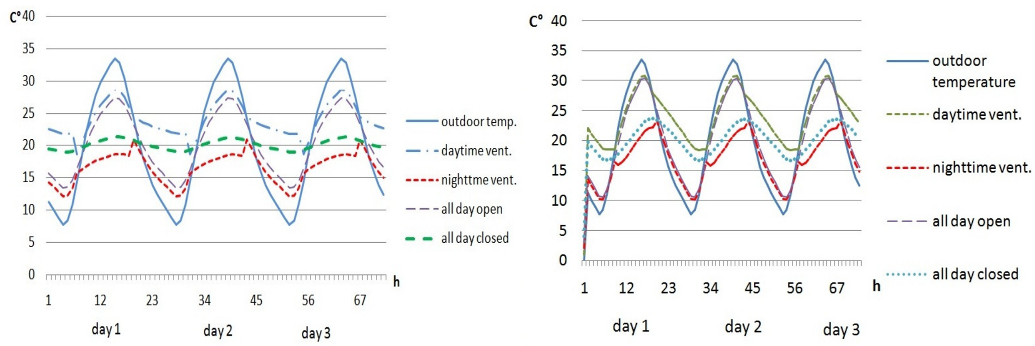


Figure 6. Nighttime ventilation effects on a clear sunny day in July



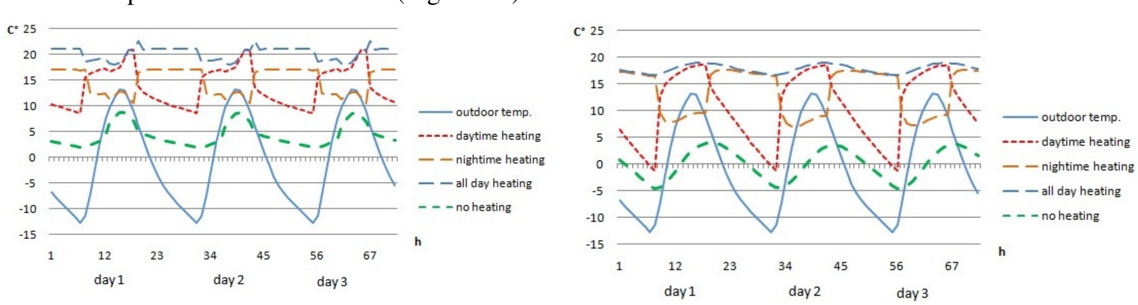
a) b)

Figure 7.a) Ground floor, summertime room air temperature fluctuations according to different ventilation modes b) Upper floor, summertime room air temperature fluctuations according to different ventilation modes

3.3.2. Winter heating mode

The winter outdoor temperature fluctuations between possible maximum and minimum temperatures values can be significant (Figure 8). Ground floor's high thermal mass, as well as the First floor's, provided heating throughout the day (at 21°C), secures the constant comfortable temperature of the interior spaces.

Comparing the thermal performance of the Ground floor and First floor, better performance in winter moths has been observed on the Ground floor. Very thick masonry walls, from 44 to 65cm, with significant thermal mass, unsurprisingly, provide good insulation quality. When kept closed all day, without heating, Ground floor quarters keep the temperature between 2°C and 8°C even when the outside temperatures are at extremes (Figure 8.a).



a) b)

Figure 8. a) Ground floor heating modes **b)** Upper floor heating modes

Since the thermal performance of the house in its original state provides relative thermal comfort only in the case of constant heating regime, there was a need to test possible thermal performance improvements of the house by adding thermal insulation. Two additional performance scenarios have been simulated for both of the floors. These scenarios include adding insulation on the outside or inside of the existing wall structure, consecutively (Figure 9&10).

Thermal performance simulation for either of the floors, as well as comparative analysis of the results, showed that the most favorable scenario, among multiple combinations of heating hours and insulation positioning, is the case where the thermal insulation has been installed on the outside of the existing structure (Figure 9). In afore mentioned case the drop of room temperature, in the non-heating hours, is not as drastic as in the case of non-insulated (Figure 8) or inside insulated existing structure (Figure 10). Better thermal performance, due to high thermal mass, also implies decrease in heating load. This study can be used as a reference in efforts to improve energy efficiency and thermal comfort of the existing housing.

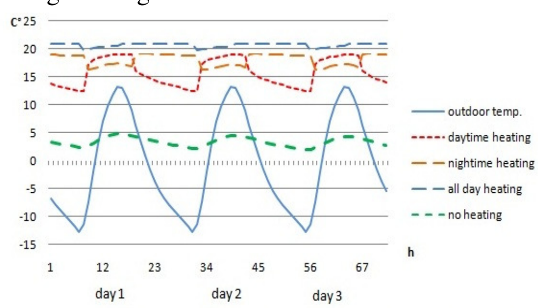


Figure 9. Ground floor:
Winter heating mode with additional thermal insulation *outside* of the existing structure

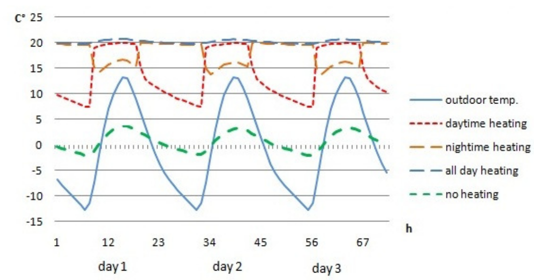


Figure 10. Ground floor:
Winter heating mode with additional thermal insulation *inside* of the existing structure

3.4. Site measurements

A field survey was conducted throughout the TBT house the using Mother Tool-LM-8000 measuring device. Measurements of indoor and outdoor temperature, humidity and wind speed were taken on two winter days, with extremely different conditions: 23rd of January, an unusually warm day with partly cloudy skies and observed outside temperature of 12°C and 25th of January, cloudy skies with snow and the outside temperature slightly below 0°C.

Since the house is used as a museum, some of the rooms are kept open and some are kept closed during most of the day (during working hours) so that the effects of *all day closed* or *all day open* ventilation modes could be observed. On a warm day, inside recorded temperatures in *all day closed - no heating mode* were slightly lower (8,7 to 10,7°C) than the outside 12°C, and on the cold, snowy day the opposite was true, with inside recorded temperatures (4,5 to 8,5°C) were higher than the outside temperatures (-0,7 to 0,2°C) by 4 to 8°C.

Although similarities between site measurements and software simulations are evident, the site measurements conducted are not to be considered as a final and cogent evidence of the house's thermal performance since they were executed in an only limited time frame. They can instead be taken as an encouragement for future filed measurements and studies.

4. CONCLUSION

The analysis of the architectural elements of the traditional Bosnian town house as well at the computer-aided simulation of possible scenarios in terms of achieving optimal thermal performance, showed positive results. The house indeed demonstrates good performance in the wintertime, similar to that of appropriately insulated contemporary housing. It was discovered that in the summertime, the combination of different architectural elements (*divanhana*, deep eaves, pavilion type of layout, gardens and courtyards, massive walls) and techniques (cross ventilation, night-time cooling) contribute to the thermal comfort of the house. These architectural elements and techniques have the potential to change the face of contemporary Bosnian architecture, if utilized properly. Seeking the lost connection with vernacular architecture means re-establishing the most natural way of living, the one in tune with the natural environment. Including vernacular passive elements into contemporary designs is expected to contribute in achieving more energy efficient and comfortable lifestyle while paving a new way to sustainable architecture in Bosnia and Herzegovina.

5. ACKNOWLEDGMENTS

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Solar Control in Traditional Architecture, Potentials for Passive Design in Hot and Arid Climate

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ABSTRACT

This paper is a part of a research work that targets the evolution of traditional architectural features to develop a passive design strategy for contemporary buildings. It counts on the building as a self-climate modifier in hot and arid climate. The traditional house demonstrates awareness of solar geometry and heat transfer mechanisms as basic physical principles which govern the heat gain/loss process within the building. The work in this paper is confined to examining the effect of traditional solar controls and shading mechanisms. Discussed features are the resulted cross shading in narrow street canyon and window screens. The suggested features were introduced as shading devices to an existing contemporary building within consecutive simulations using TRNSYS 17. The climatic data for Cairo as a case study was considered. The simulation model was tested against indoor temperature and validated by comparing results to measured data. The model then was modified by introducing suggested features which found to be comparatively effective in lowering the indoor temperature.

INTRODUCTION

An abandon of studies showed that the basic principle of traditional building was to accomplish a couple of goals; fulfill privacy; and achieve comfort. These purposes were fulfilled through a passive design strategy applied within urban setting, building form, and building envelop. The analysis identified some key components and other subsidiary elements. The main common aspect is the duality of nature of these key elements through which both thermal comfort and privacy were achieved. This paper focuses on the role of shading systems; street cross shading; and window screens, on reducing indoor air temperature in hot and arid climate regions with reference to the Egyptian capital Cairo.

Cairo is located on 30.0566° N, 31.2262° E in the North East side of the African continent. As most of the countries in its region, Cairo is characterized by a typical hot and arid climate that receives an average annual sum of 3000 hrs. Air temperature exceeds 40º C in the summer, **as shown in figure 1**. The climate in general is characterized by large diurnal temperature differences which allow intense solar radiation during the day and quick cooling down at night. These characteristics impose special considerations upon building design and the urbanization process in general, especially with regards to the solar geometry. The direct solar radiation intensity is up to 814-930 W/m2 on the horizontal surfaces. Solar radiation is direct and strong during the day, but the absence of clouds permits easy release to the heat stored during the daytime, in the form of long-wave radiation towards the sky during night-time (Fathy, 1973). The solar radiation on horizontal surfaces reaches the highest range in June; 7.45 KhW/m²/day in Cairo. Egypt receives an average between 5.4 and 7.1 kWh/m² of annual daily direct solar radiation, **as shown in figure 2**, from north to south (Robaa, 2006).

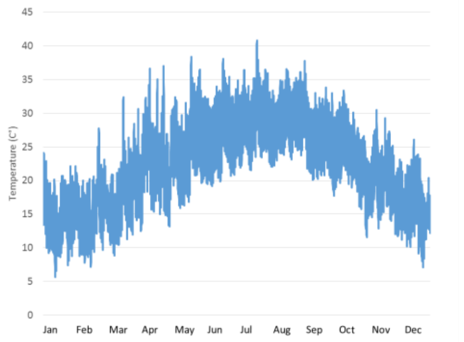

Figure 1 Daily temperature chart for Cairo

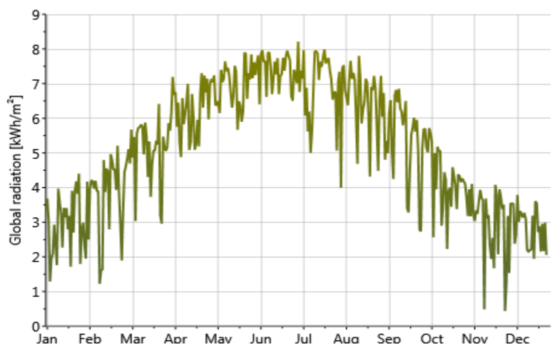

Figure 2 Daily global radiation chart for Cairo (source: Meteonom 7)

Determination of the daily and annual sun path is essential to calculate the solar intensity of radiation hits the building (Hausladen, de Saldanha, & Liedle, 2006). It also helps to predict the resulted shadows and hence the placement of shading devices (Datta, 2001). A stereographic projection of the sun path shows both angles of altitude and azimuth as a diagram for the sun path which can be applied to each latitude. **Figure 3** shows the sun path diagram for Cairo, the sun position at 15:00 hrs. in April 24, the period during which measurements took place for this study. The old town is characterized by almost narrow urban canyons with aspect ratio, height to width H/W = 2, **as shown in figure 4**. As the street width is proportional to the building height, the percentage of overshadowing one building by the other, obstruction angle (ɵ), remains constant for different building heights (Bansal, 1994).

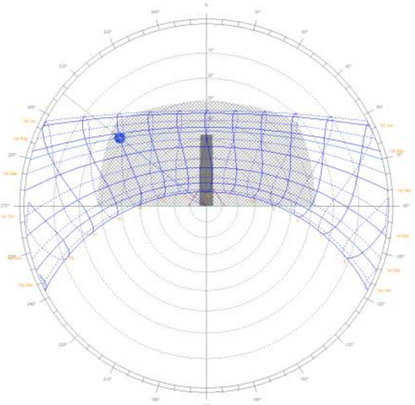

Figure 3 Stereographic projection of sun path, Cairo at 15:00 hrs. in April 24

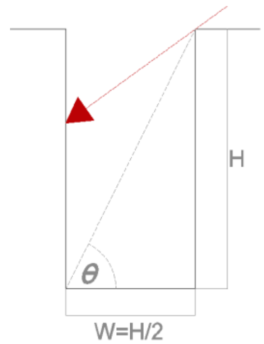

Figure 4 Building shading in relation to aspect ratio

Some recent studies focused on the influence of cross shading, orientation, and proportions of the street canyon on temperature differences. The following results were observed: a study focused on street canyon cross shading concluded that air temperature in the narrow urban canyon (H/W = 2) decreases by 4 °C compared with the wide urban canyon (H/W = 0.5) because of the lower solar gain in summer. A latitude of 33°N, EW street orientation can achieve shading of about 30% for an 8-month period in a year, with aspect ratio, H/W 2:1 or higher. The ratio 0.5:1 is least effective even with NS street orientation, less than 35% street shading (Bourbia, Awbi, 2004)

In 2006 Georgakis and Santamouris showed that ambient temperature above the canyon is found to be higher than the temperature inside the street with maximum of 5°C (Georgakis, Santamouris, 2006) The duration of solar radiation incident on both the east and west facades simultaneously was less than 3 hours in a traditional narrow canyon. The NS street orientation for H/W = 1.5:1 and higher can result in street shading between 40 to 80% of street area, whilst diagonal street orientations NW–SE (S2, S3) and NE–SW (S5, S6), can only manage street shading between 30 to 50% of street area throughout the year.

Studies have proved that incorporating overhangs depending on the different mean azimuth angles for summer and winter direct sunshine decreases the thermal gain through the building. For vertical glazing shaded by horizontal overhangs facing south, the rate of heat transfer into the building was 75 Wm² lower than unshaded windows, for June 21 (Askar, Probert, and Batty, 2001). It has been proven that the use of window screens in hot climates reduces the cooling loads and the perforation ratio of the screens influences the inside temperature. Simulations were applied to screens on west, south, east and north facades and an ultimate ratios were proved as achieving the highest rate of energy saving. Proposed ratio between the width and depth was 1:1 with an 80% perforation in the west and north orientation and 90% in east and south. In comparison with non-shading windows, the energy savings resulted from the use of these screens reached 30%, 30%, 25% and 7% for the west, south, east, and north orientations. (Sherif, El Zafarany, and Arafa, 2012).

METHODOLOGY

The methodology of implementation of this paper was to test the indoor air temperature of an existing contemporary building which adopts the modern construction method prevailing in Cairo. The selected case study was intended to compromise the major opposites to the suggested features which would be introduced to the simulation package in TRNSYS to compare results with those of the base case and hence determine the extent to which those features can influence the indoor temperature. In order to validate the model generated in TRNSYS, in-site measurements took place within a certain timespan, which were then compared to the simulation results that found to be quite identical.

Case Study

The selected case is located on the eastern borders of Cairo within a residential quarter in the district of Heliopolis called the Sheraton Housing Area. **Figure 5** shows a satellite image of the site. The monitored case exists in the first floor of a nine-story residential building on a ground floor area of 310 m². Each floor consists of two identical apartments with an area of 135 m². The main façade is south-west oriented on a main street with 75 m. and a central green area, **shown in figure 6**. The building is a concrete structure and its walls are of hollow red bricks with density of 1790 kg/m³, thermal conductivity 2.1 kJ/hmk, and specific heat 840 J/kg.C according to the Egyptian code for Buildings. Windows are 6mm. single clear glass with aluminum frames and all doors are made of wood. Parquet timber flooring is applied to the monitored case. The monitored room, shaded in the floor plan, **figure 7**, is the main living area of the western apartment in the first floor. The room is overlooking the main street through a relatively wide window 6 m², about 54% of the wall with no shading device. The case shows a lack of any cross shadings from opposite buildings except for the building facing the north east façade.

Figure 5 Location and urban setting

Figure 6 General view

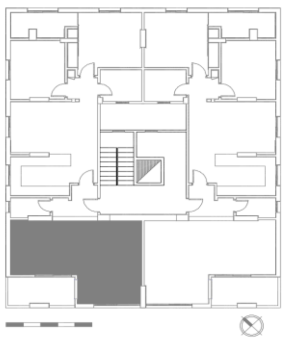

Figure 7 Floor plan

Table 1. Building description

Item	Description
Location	Eastern borders of Cairo
Building type	Residential
Ground floor area	310 m²
Wall material	Hollow red bricks
Skeleton	Concrete
Wall thickness	10-20 cm
Slab thickness	12-18 cm
Windows	6 mm. single clear glass with aluminum frames

Table 2. U-value of material

Material	W/m²K
External wall (solid red brick 20 cm. and 2 cm. plaster	1.82
Internal wall (solid red brick 10 cm. and 2 cm. plaster	2.65
Internal floor (concrete slab 18 cm. and massive wood floor)	0.71
Roof (concrete slab 12 cm with stereo-pore insulation and tiles)	0.45
Glazing (6 mm. single glass)	5.6

Measurements

Filed measurements took place for indoor air temperature of the selected room for one week long from the 18th to 25nd of April using temperature data loggers hanged from the ceiling of the space on a height of 1.7 m. To get more plausible results, two data loggers were installed in the room, one facing the window directly overlooking the street and the other facing the balcony **as shown in figure 8**. A temperature data logger was as well placed outside in the balcony to get real ambient temperature records. The data loggers used are HOBO U12-012. According to the manufacturer, the measurement range of the loggers are -20° to 70° C and 5% to 95% RH. The accuracy of the loggers is ± 0.35° C from 0° to 50° and ± 2.5% from 10% to 90% RH. The loggers were set to continuously take readings each 10 minutes. The space was vacant and totally closed during the measurements periods and no cooling system operated. The results of the field measurements are **shown in figure 9**.

Although the selected period is not the best to represent the hot climate of the region, it was quite adequate for validation of the simulation model that should be tested against real measurements. Moreover, a comparatively high temperatures which reached a maximum of 38° C were recorded, which closely matches the hottest summer days. The weather data for Cairo was obtained on daily basis during the measurements period and a week before from the NOAA (National Oceanic and Atmospheric Administration). The obtained data included hourly records which were subsequently used to create a weather data file that was given to TRNSYS to run the simulation. Some differences were traced between the values of the measured ambient temperature, especially for the minimum values, and those of the obtained weather data which found to be 4° C less in average **as shown in figure 10**. This could be attributed to the differences between both sites of measurements as the weather data is obtained from the weather station that installed in Cairo Air Port in a totally open spacious and un-urbanized area. This is quite different from the site in which the readings were recorded; within relatively dense urban fabric in which the measured temperature should be influenced by the heat island effect and the heat released from the buildings during night-time cooling.

a)  b)  c) 

Figure 8 (a, b, c) Data loggers installation

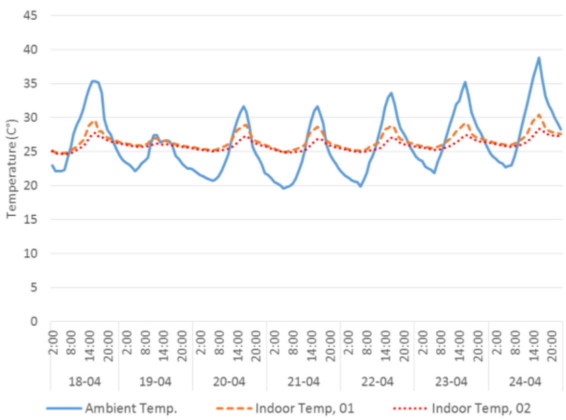

Figure 9 Real Measured Temperatures

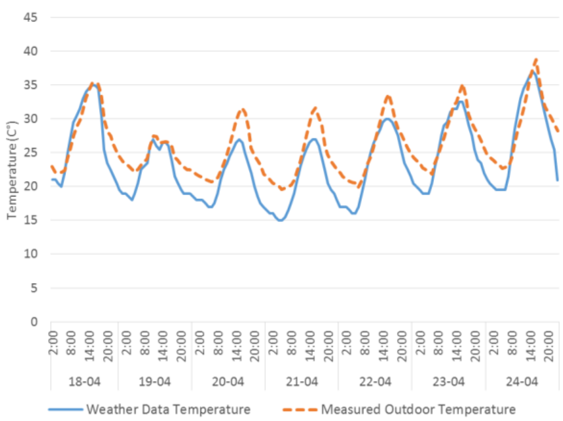

Figure 10 Measured outdoor temperature against real weather data

Simulation Package

As the main concern of this stage was to validate the capacity of the simulations by comparing their results to those of the real in-site measurements, a model of the selected case has been created and all related data was given to TRNSYS 17. A 3D model was created by TRNSYS 3D, **as shown in figure 11**, and the previously mentioned construction materials and their thermal properties, **as shown in tables 1 and 2**, were entered in TRNSYS Build. Simulation has run for the selected timespan and five days before upon the created weather data file. Initial values for indoor temperature was set to 21° C and relative humidity to 50%. A comparison then was carried out between the simulation results for indoor temperature of the selected room and the measured values.

Figure 11 Model of the case study created by TRNSYS 3D tool

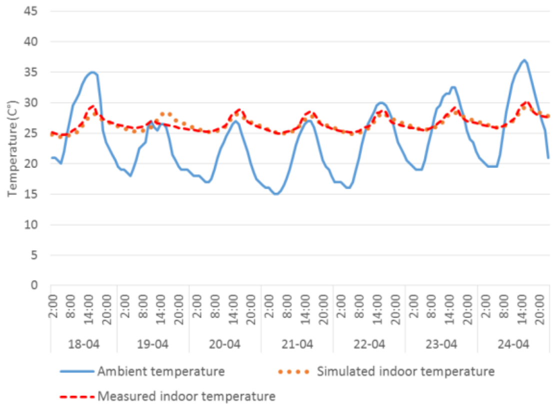

Figure 12 Simulation results for indoor temperature against measured data

The results, **shown in figure 12**, demonstrate remarkable conformity between both profiles of measured and simulated indoor temperature which reaches a maximum of 30° C and a minimum of 25° C in both cases. As described above, the space was closed all along the measurements period and hence no ventilation or infiltration rates were applied. This might explain the relatively narrow gaps between maximum and minimum temperatures as it limits the chances for the occurrence of effective night-time cooling. Ventilation and the role of wind velocity can be discussed within subsequent paper that focuses on the role of the courtyard, as the work of this paper is confined to discussing the shading devices and the response to the solar factor.

Experiments

The main objective of this paper is a preliminary examination of the effect of the traditional shading methods on indoor air temperature in hot climate. As long as simulation results for the basic case were found to be similar to the measured data values, experiments could take place by incorporating the suggested features into the created model and hence results could be compared to those of the basic case to assess potential influences. Two major experiments then took place as follows:

Narrow Street Canyon, Cross Shading. The old traditional city was always characterized by dense urban fabric and narrow streets that generally form deep narrow canyons with average width of 7 cubits. This formation resulted in subsidiary streets which are almost east-west oriented being shaded along the day. The case studied in this paper represents an extreme opposite to this situation with a street width of 75 m., which supposedly played a significant role in the relative high indoor temperature. According to the west-south orientation of the main façade, it would be then exposed to the direct solar radiation especially from the middle of the day on.

This experimental step proposed a building opposite to the main façade and as the same height as the monitored building, leaving a street width of 6m, which creates a relatively deep narrow street canyon with aspect ratio much over 2. Although the case of adding a building in front of another is unlikely to happen within existing urban settlement, this experiment is applied to demonstrate the effect of narrow street canyon cross shading if being considered within urban development that take place in the future. It was added as a shading device in TRNSYS 3D model, **as shown in figure 13**. An updated shading matrix was then generated in TRNSYS Build and the simulation has run as the same as the basic case in terms of period, material properties and other parameters. The results showed a significant decrease in indoor temperature that averages 4° C when compared to the values taken from simulation of the base case, **as shown in figure 14**.

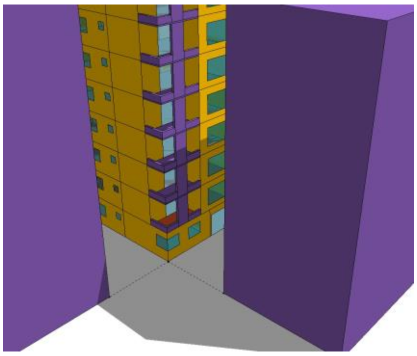

Figure 13 A building opposite to the south-west façade added as a shading device

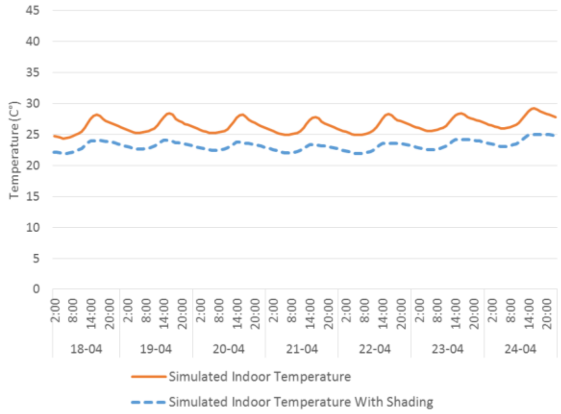

Figure 14 Simulation results for Indoor air temperature with cross-shading compared to base case

Window Screens. Another shading device was added which is a window screen. The screen was incorporated to the window on the south-west façade. The window occupies an area of 6 m², about 54% of its wall. The screen was designed with modular sections of 5x5 cm. with proposed ratio between the width and the depth 1:1 and 50% perforation, **as shown in figure 15**. The resulted exposed glazing surface was then 19%. The simulation has run with new shading matrix generated and without opposite building. The results showed also decrease in maximum indoor air temperature with average value of 2.5° C, **as shown in figure 16**.

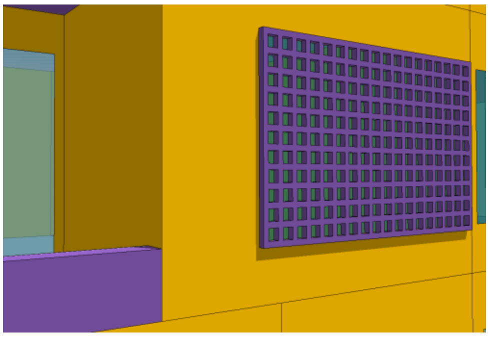

Figure 15 A window screen incorporated on the south-west façade

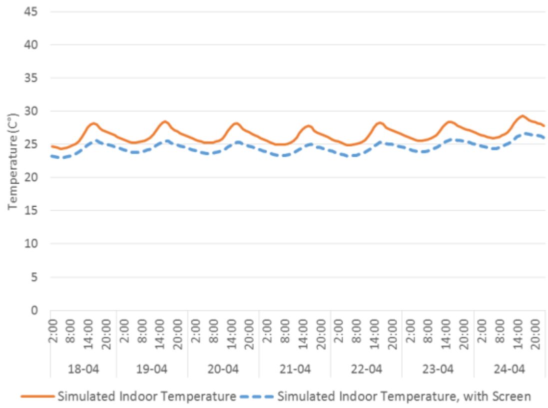

Figure 16 Indoor air temperature after adding a window screen compared to basic case

DISCUSSION

It is quite relevant that the first case in which an opposite building exists is found to reflect better thermal performance, **as shown in figure 17**, this could be attributed to a couple of factors. First is that the entire façade is shaded by the opposite building not only the shaded proportion of the window. Hence the transmitted solar radiation into the space would be significantly reduced, **as shown in figure 18**. The second factor is the role of resulted reduced outdoor temperature of the street and hence the façade temperature. In this case when the sun hits the surface of a building in a street canyon, convective current results as the air density changes the hot air moves to the upper level and be replaced with cooler air which has greater density, **as shown in figure 19**. The exposure of gap to the night sky enhances the night time cooling since the heat radiates up to the sky. The street is cooled down during night and daytime unless the sun is coming on a vertical angle. However, this could be discussed within a following paper.

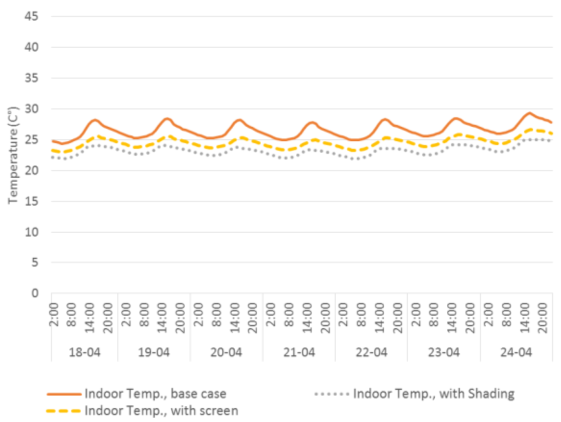

Figure 17 Comparison between the three situations

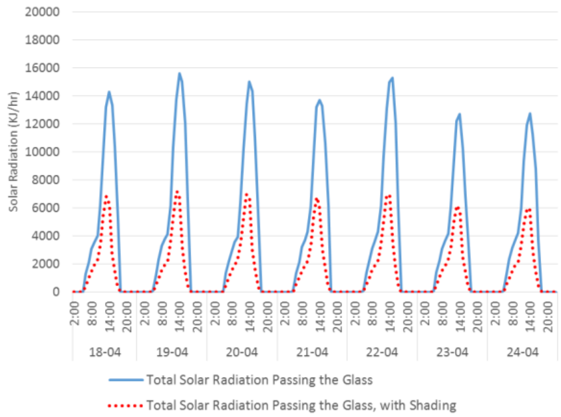

Figure 18 Total solar radiation transmitted through the glass; with and without a shading

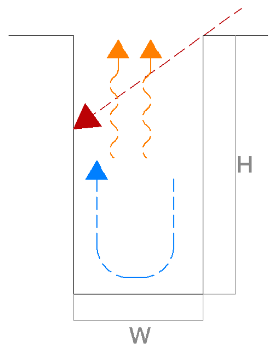

Figure 19 Convective current in street canyon

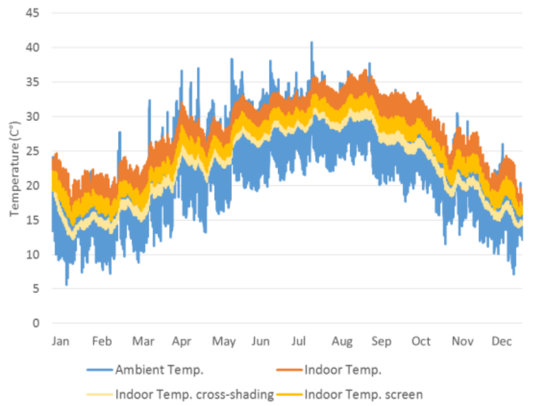

Figure 20 Annual profile for indoor temperature comparing base case with both suggested cases

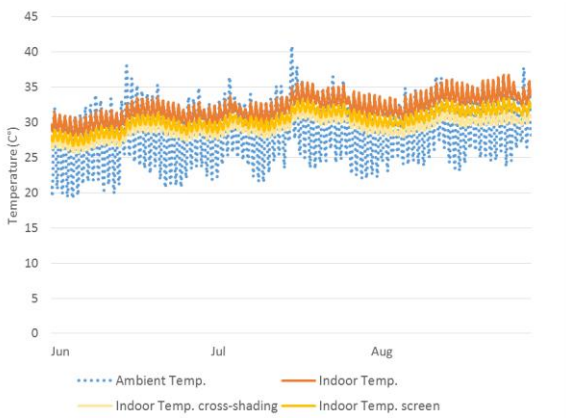

Figure 21 Summer profile for indoor temperature

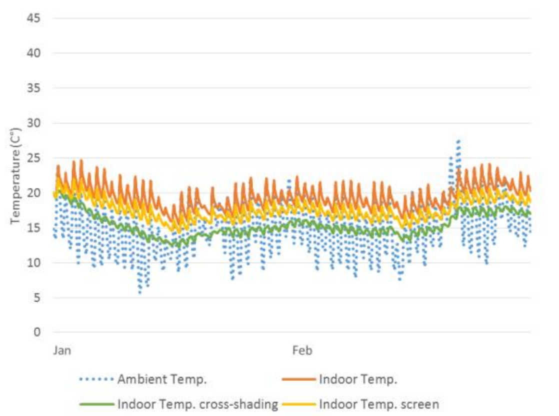

Figure 22 Winter profile for indoor temperature

To predict the performance of the suggested features during the hottest summer days, simulations have run for the base case to a year time span, **figure 20**. The same experiments were applied upon yearly weather data and a relative differences were found for maximum temperature in both cases within summer days in July and August, **as shown in figure 21**. In winter days however, the case of cross shading condition showed comparatively dramatic decrees in indoor temperature during January, **as shown in figure 22**. As the length of shadow on a wall surface can be determined, in relation to solar geometry, by horizontal and vertical shadow angles, **as shown in figure 23**. The decrees of indoor temperature could then be attributed to the position of the sun being too low in the sky and the opposing building that would almost block the radiation that would not reach the lower floors which remain shaded all the time, **as shown in figures 24 a-b**. However the window screens would be less effective in winter due to the limited shading resulted by the angle of the sun beam, **as shown in figures 24 c-d.**

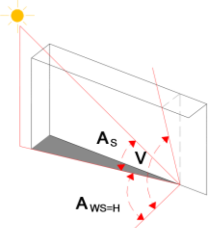

Figure 23 Shadowing angles
V= vertical shadow angle,
H=horizontal shadow angle

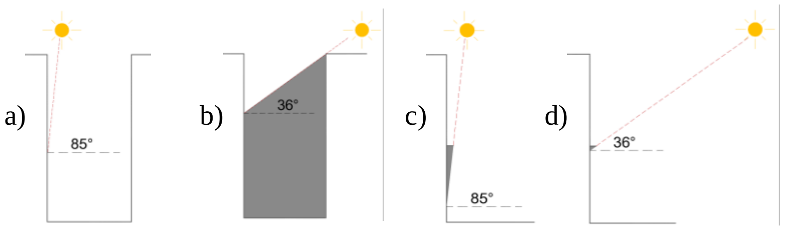

Figure 24 Resulted shading by sun angle:
a-summer sun with cross shading, b-winter sun with cross shading,
c-summer sun with window screens, d-winter sun with window screens

CONCLUSION

Solar control was achieved within the old city on both levels of urban density and building envelop. The orientation of main roads in the old town is north-south; however the secondary streets of the residential quarters are east-west oriented. The buildings as a cluster therefore are shading each other. The amount of shading depends mainly on the morphology of the street canyon which results in decrease in the canyon temperature and hence the façade temperature and subsequently the amount of heat transferred by conduction through the walls. The incorporation of window screens also contributes to lower the indoor air temperature in hot and arid climate. The screen acts as a baffle zone between the interior and the exterior, so the glare of sunlight is broken up by the lattice that provides a dark area. By introducing both techniques to a contemporary building by running simulations using TRNSYS it is found to be relatively effective in reducing maximum indoor temperature in hot weather. However, the suggested features can be more efficient when applied within future researches considering convective current resulted in narrow street canyons and the role of cross ventilation in night-time cooling.

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Kampong Ayer: A Community Living on Water in Brunei Darussalam

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ABSTRACT

Land scarcity and rising population in developing countries, particularly in the urban parts of Asia, has led to limited livable floor area for domestic mass housing. Developing countries with similar climate and cultural background face common challenges with their comparatively larger population resulting in high-rise housing. While this may be a solution to accommodating the increasing density in many cities, issues relating to cultural preservation, vernacular architecture conservation, social structures, environmental comfort and sense of community are often in contradiction with this urban solution. In particular, with for a rural community with different characteristics to an urban intent, the transition might prove stressful. In Brunei Darussalam, encouraging living both on water (in Kampong Ayer) and on land is what is being currently proposed. However, as its population is rapidly increasing and living on land is becoming increasingly popular, in this paper, the authors question if the housing developments on the water in Kampong Ayer, promote a sustainable community. The authors explored if waterside housing development, modelled on traditional settlement patterns, can provide a viable solution for rural housing in parts of Brunei. Domestic and communal relationships of its inhabitants were defined to identify sociospatial patterns of a sustainable community. Findings include the correlations between the formal and spatial organization of the home and patterns of occupation.

INTRODUCTION

The modernisation of rural communities into the urban ones may have many benefits in theory, but over time and with population growth, this tends to develop limitations. This is largely due to incompatible solutions imposed on these communities, resulting in their inability to adapt to them. To move forward, it is necessary to take a few steps back and examine vernacular architecture for a better understanding of how communities lived independently and built their own houses (Oliver, 1969). In as much as vernacular architecture in housing has often been associated with squatters and illegal settlements such as the favelas in Brazil, these self-built houses frequently offer insights into community spatial requirements. Indeed, learning from the past can encourage a stress-less human adaptability process (Roaf, 2010).

The Kampong Ayer, or ‘Water Village’, located in Brunei's capital city Bandar Seri Begawan, houses around 39,000 people in self-built homes on stilts that form a unique architectural heritage that has been occupied for over 1300 years. Thirty years ago, the ‘discovery’ of the urban poor’s ingenuity in building their own houses generated a significant amount of research interest and subsequent literature (Ward, 1982). Similarly, studies that covered the technical performance of this type of housing, such as thermal comfort, were undertaken separately. However, it is suggested that a combination of both technical and socio-cultural issues would be more effective (Evans, 1980). For instance, while the performance studies into technology developed to combat climate change have been successful, the technological capability of the community to fully utilise such technology is questionable (Hyde, 2008). It is suggested that the compatibility of technical and social solutions with regards to managing the urban poor needs to be in accordance with the local habits and preferences of the people (Labaki and Kowaltowski, 1998). Often we are unsure of what these local habits and preferences are. Nonetheless, a typical place that reveals such information is the house. As such, perhaps the first step towards understanding rural communities is to examine the role of the house and appreciate its significance to the community (Waterson, 1990). Gaining a deeper appreciation and understanding of the meaning and perpetual variables encapsulated in the house by examining patterns of daily domestic activities can give a clearer explanation of how it came to be rather than the end product itself (Rapoport, 1969).

Developing countries with similar climate and cultural values face common challenges with their comparatively larger population and often resort to high-rise housing. Brunei Darussalam, with a relatively small population of fewer than 400,000 people, has a less urgent agenda but equal concern for the sustainability of its future housing. In 1910 the attempt to relocate some residents of Kampong Ayer (around 10% of the total population) into housing estates on land began. However, as its population continues to grow and living on land becomes increasingly popular, a tailored sustainable housing approach for communities living on water may be needed to preserve and sustain Kampong Ayer. As the majority of the residents who reside there are low-income earners, it is of even more importance to resolve its housing issue (Sullivan and Ward, 2012).

In this paper the authors present an investigation into the evolution of spaces, from the 1950's to the present day, of six houses in Brunei Darussalam, by analysing the daily life patterns registered on the floor plans of each house using a system developed by the authors. As there is limited detailed evidence of the daily activities, which occurred in the houses historically, it was not be possible to make any definite comparisons. Therefore, most of the work described in this paper was based on the actual findings from the field investigations.

Background

According to the Brunei Malay Technology Museum, 1989, there are five basic house types found in Kampong Ayer. Of these, the plan layout of two houses, 'Tungkup' and 'Berlanggar', best showed similarities to the case study houses, as they bore a strong resemblance to the current houses (Fig. 1). These simple open plan layouts suggest a communal use of gathering space as is typical of Malay houses found in the Malay Archipelago region. Typical characteristics of this house type were considered to create a datum for this discussion. In reference to a typical Malay house (Fig. 2), it is suggested that the floor plans demonstrate its multi-functional purpose, influenced by the time of day and year, minimal physical partitioning and furniture, and with most activities utilising the floor (Lim, 1987). Physically, the interior spaces are not defined by walls and are instead distinguished by differences in floor levels, varying floor sizes, orientation and location.

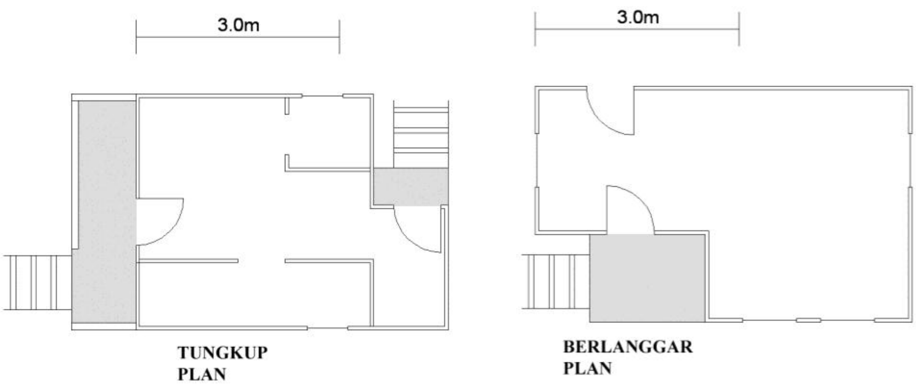

Figure 1 Two Houses types, Tungkup (left) and Berlanggar (right) in Kampong Ayer, Brunei Darussalam as recorded by the Brunei Museum (Redrawn by authors).

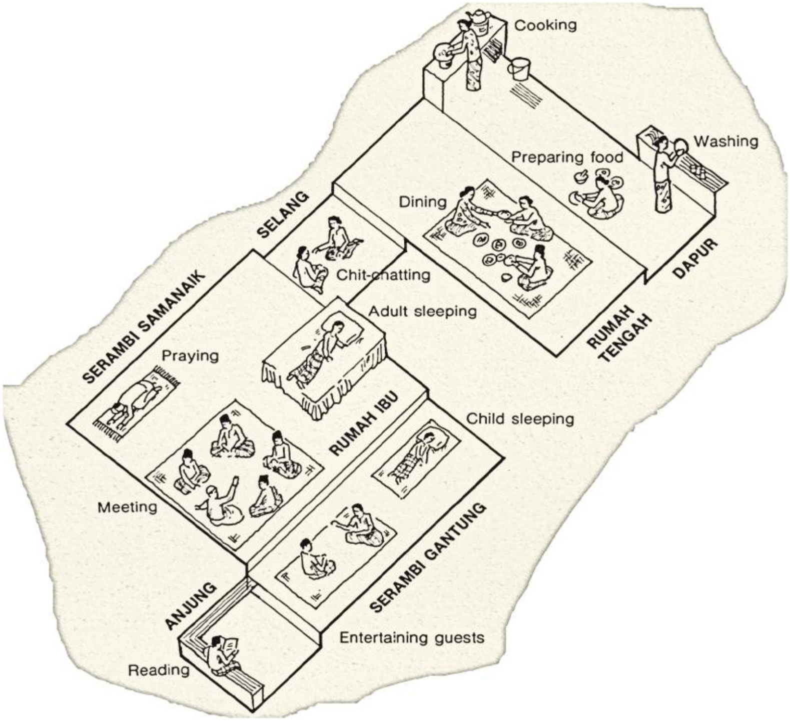

Figure 2 Use of Interior Spaces in Traditional Malay house (Source: Lim, 1987. Page 36)

METHODOLOGY

The houses were randomly selected and the house owners' were each required to sign a study participation agreement. Of the houses investigated, house 1, 2, 4 and 6 were found to have more traditional layouts, whereas house 3 and 5, built in the last four years, were found to have a 'modern' layout (Fig. 3). A summary of the characteristics of each house is given in Table 1. The investigation involved having the house occupants mark occupancy charts for each room in their houses, so as to map the frequency of and time when the rooms were occupied. The information marked on these charts showed the most commonly used rooms in the house as well as the number of people occupying the room at hourly intervals throughout the day, for period of 4-6 weeks.

Additionally, using Tinytag data loggers, the recording of internal temperature and relative humidity of the four most occupied rooms in each house was conducted simultaneously. To shed more light on the results of the occupancy investigation, interviews (partly based on findings from initial results of the study) with the house owners were undertaken. In addition to this, a survey was carried out with the intention of giving a general view on the living conditions of the people in Kampong Ayer. Some results from this survey as related to the selected houses are discussed later.

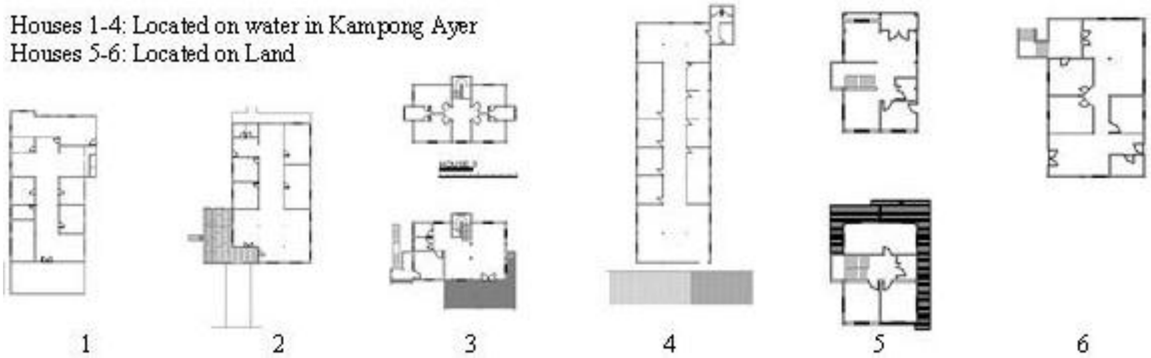

Figure 3 House plans of six houses (Source: House 1, 2, 4 & 6 from authors; House 3 & 5 from Public Works Department and Housing Development Department, Brunei Darussalam, respectively).

Table 1: Brief Descriptive Comparison of the Six Houses

HOUSES	1	2	3	4	5	6
Number of people living in the house	4	5	14	15	6	4
Main House materials	Timber	Timber	Mixed	Timber	Concrete	Timber Concrete
Number of bedrooms	5	3	4	8	3	2
Total floor area (m^2)	211	194	203	336	122	105
Number of families Living in the house	1	1	2	3	1	1
Self-build / New build	Self-build	Self-build	New build	Self-build	New build	Self-build

OBSERVATIONS

Sleeping arrangements were found to depend on the number of people living in the house and number of bedrooms available. For households with sufficient bedrooms, everyone was assigned to a group sleeping area. For instance, for a typical family living in a three-bedroom house, the parents shared a bedroom, while groups of the male children and female children had a room each. Babies and younger children often share a room with their parents whereas young male and female children can share a room only if there is no other room. Segregating the children at an early age is partly influenced by the Islamic religion - the main religion practiced in Brunei Darussalam. Often, in deciding who gets a bedroom, female children are given priority over male children. Such was the case in House 3 where a family of fourteen living in a four-bedroom house allocated rooms in the following manner: Bedroom 1 – parents; Bedroom 2 – three daughters; Bedroom 3 – eldest daughter, her husband and their two young children; Bedroom 4 – second eldest daughter who is engaged to be married (her future husband will share the room with her); Living Room - three sons (one son sleeps in the communal space in the bedroom lobby at night). It was found that an insufficient number of bedrooms compelled families make use of other rooms in the house for sleeping, commonly the living room or family TV area. The bedrooms have beds while the living room or family room will have mattresses on the floor, which are rolled up and put away during the day.

Areas for sharing meals varied in all six houses. House 1 had a dining area next to the kitchen area, used for the main meals. On the other hand, House 5 had a dining table in an area separate from the kitchen, which was also used for main meals. House 2, 3, 4 and 6 each had a small table in the kitchen where the families could gather at mealtimes. Sometimes this involved moving furniture to accommodate everyone. Occupants of House 1, 5 and 6 had all their meals at their table at regular times of the day, whereas occupants of House 2, 3 and 4 had irregular meal times with some meals taken in different parts of the house such as the family TV room. With the exception of House 3 where the head the family occasionally used meal times as an opportunity to hold family discussions, it was noted that meal times were viewed mostly as a time for eating instead of dialogue. In addition to providing space for informal dining, the kitchen was used for cooking and as such its floor area is sufficient to accommodate just this. Also, the kitchen is usually modified to accommodate kitchenware storage and large freezer units. As fresh meat is not readily available, families bought in bulk to store until the next shopping trip in the city.

Common to all six houses was the popularity of the family TV area as the main gathering zone for family members. This took place mainly in the evening, after dinner and the last prayer of the day, at around 8.00PM. Rarely used for informal family gatherings, the living room is mostly used to receive guests. During special occasions and events involving many guests, all the communal areas in the house are occupied to accommodate everyone - including in the corridors. Furniture is moved to create more open spaces and carpets are rolled out on the floor for guests to sit on. As with the sleeping arrangements, females and males tend to group separately further highlighting gender segregation in spatial use, as is influenced by Islam.

Traditionally, the front of the house has an outdoor area, the veranda, which is used for less formal gatherings or as an introductory area before entering the house. Usually, this is the first area to be renovated so as to extend the living room area. As a small roof or a large over-hanging roof already covers this space, it requires only three external walls, windows and a new entrance to do so. This newly extended room is commonly utilised as a living room or small shop (Fig. 4). In House 4, the existing living room is large enough to accommodate a small shop indoors (Fig. 4). However, the extension option was found to be more common possibly due to occupants wanting to keep indoor areas inaccessible to the public.

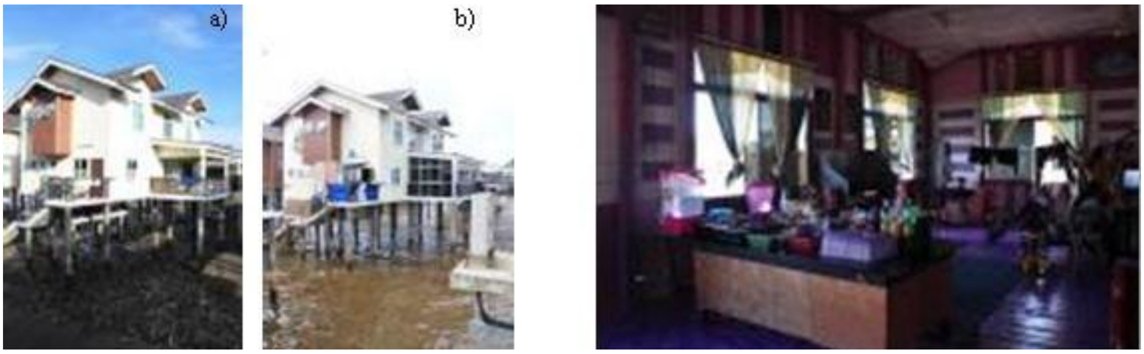

Figure 4 Left: House 3 before and after conversion of the veranda into a shop (a) December 2012 (b) January 2014. Right: Showing the living room in House 4 that has been modified to accommodate a small shop (Source: Author).

RESULTS FROM THE OCCUPANCY INVESTIGATIONS

Tables 2 and 3 show some results of the occupancy investigations. Table 2 reveals the bedrooms and the family TV room to be the most frequented spaces. Specifically, a large duration of the time spent in the bedrooms is spent sleeping (between 9.00PM and 5.00AM) but is also occupied for short afternoon naps and performance of daily prayers during the day. As was highlighted earlier, the family TV area is occupied more frequently than the living area as it is less formal and allows the families to gather there to rest, watch TV and carry out a variety of activities. Also shown is the amount of time spent in other areas in each house where/when each family conducts other daily activities.

Table 2: The Most Frequently Occupied Rooms in Each House

House	Three Most Occupied Rooms in Each House with Percentage of Occupancy (On average in a day) As recorded between 6th January 2014 to 13th February 2014					
	1		2		3	
1	Family TV	71%	Bedroom 2	67%	Dining	67%
2	Bedroom 1	92%	Family TV	71%	Bedroom 2	63%
3	Bedroom 1	100%	Bedroom 3	100%	Family TV	100%
4	Living	100%	Family TV	100%	Kitchen	100%
5	Bedroom 2	100%	Bedroom 3	100%	Bedroom 1	92%
6	Bedroom 1	100%	Living	96%	Family TV	88%

To get an indication of the thermal comfort conditions in the houses, the temperature and relative humidity measures of selected rooms in each house was recorded. As the houses are located within the warm-humid climate zone, discomfort is more likely to be as a result of relatively high temperatures and relative humidity levels. More often than not, the main means of relief for occupants in this climate is air-movement for physiological cooling (Koenigsberger, 1974). As is typical of the Malay House, the more traditional houses were found to be structurally responsive to the climate through the provision of lightweight construction (to prevent storage of heat in the fabric), large window openings to enhance cross ventilation and air-movement as well as wide overhangs/eaves that act as sun shading elements. Some of the bedrooms had air-conditioners - only used occasionally during the night. Thermal discomfort during this time was suggested to be due to the increased number of occupants within the spaces. While the more recently built houses feature fewer passive cooling controls, it is suggested that structural modifications, such as indoor partitions have contributed to inefficiency in maintaining comfort naturally. Also, as these houses were more compact in plan, their layouts have significantly reduced the opportunities for, and efficiency, of natural cross-ventilation. Additionally, the results from the recordings were matched against the CBE Thermal Comfort Tool for ASHRAE Standard 55-2010 to determine whether any of the readings were within the predicted thermal comfort zone. Table 3 presents a snapshot of recordings taken a selected typical day – temperatures that fall within the standard are highlighted.

Table 3: The Internal Temperatures/RH levels at 2.00AM, 10.00AM and 6.00pm intervals for three most frequently occupied rooms in each house as recoded on 1.02.2014 (where available).

House	Rooms	Internal Temperature ^{o}C and Relative Humidity %		
		2.00 AM	10.00 AM	6.00 PM
1 (on water)	Family TV	-	-	-
	Bedroom 2	-	-	-
	Dining	30^{o}C / 63.9%	27^{o}C / 77.1%	31^{o}C / 66%
2 (on water)	Bedroom 1	22^{o}C / 71%	22^{o}C / 71%	22^{o}C / 57%
	Family TV	25^{o}C / 86%	25^{o}C / 86%	28^{o}C / 75%
	Bedroom 2	25^{o}C / 87%	25^{o}C / 92%	30^{o}C / 65%
3 (on water)	Bedroom 1	19^{o}C / 59%	22^{o}C / 91%	26^{o}C / 80%
	Bedroom 3	-	-	-
	Family TV	25^{o}C / 64%	26^{o}C / 77%	27^{o}C / 78%
4 (on water)	Living	-	-	-
	Family TV	25^{o}C / 86%	27^{o}C / 77%	28^{o}C / 73%
	Kitchen	25^{o}C / 88%	26^{o}C / 85%	29^{o}C / 72%
5 (on land)	Bedroom 2	-	-	-
	Bedroom 3	-	-	-
	Bedroom 1	27^{o}C / 73%	27^{o}C / 78%	27^{o}C / 74%
6 (on land)	Bedroom 1	27^{o}C / 79%	27^{o}C / 78%	29^{o}C / 67%
	Living	26^{o}C / 83%	28^{o}C / 73%	29^{o}C / 68%
	Family TV	-	-	-

Although most of the readings shown fall outside of the thermal comfort zone of ASHRAE Standard 55-2010, it is suggested that the use of structural controls (large fenestration, orientation, space volume, floor area and in some cases mechanical ventilation) and self-adjustment mechanisms helps to make existing conditions tolerable. At first glance, the readings from the houses located in the water have lower temperature readings than the houses on land. It is suggested that this is as a result of the micro-climate conditions. As the surrounding 'ground' area the houses on water is less likely to retain heat, then it is less likely for the houses to absorb heat via radiation/reflection from the ground surface, as might be the case in the houses on land. During the study it was found that external temperature levels taken in both areas showed those on land to be higher than for that of the houses on water. However, the extent to which the comparison of water and land ground surfaces and their influence on the thermal comfort in the houses will require further investigation to reach a more valid conclusion.

RESULTS FROM THE SURVEY

Results from the survey regarding the houses revealed some information about the renovations of these houses (Fig. 5). A majority of the participants taking part in this survey, live in timber houses on water, and have at some point made renovations and extensions to their house - most of which are self-built and constructed with timber. Some have integrated other materials including brick and steel. Employing contractors or foreign labourers to build the extensions is becoming increasingly popular too, which is subsequently diminishing the timber-building skill amongst the local community.

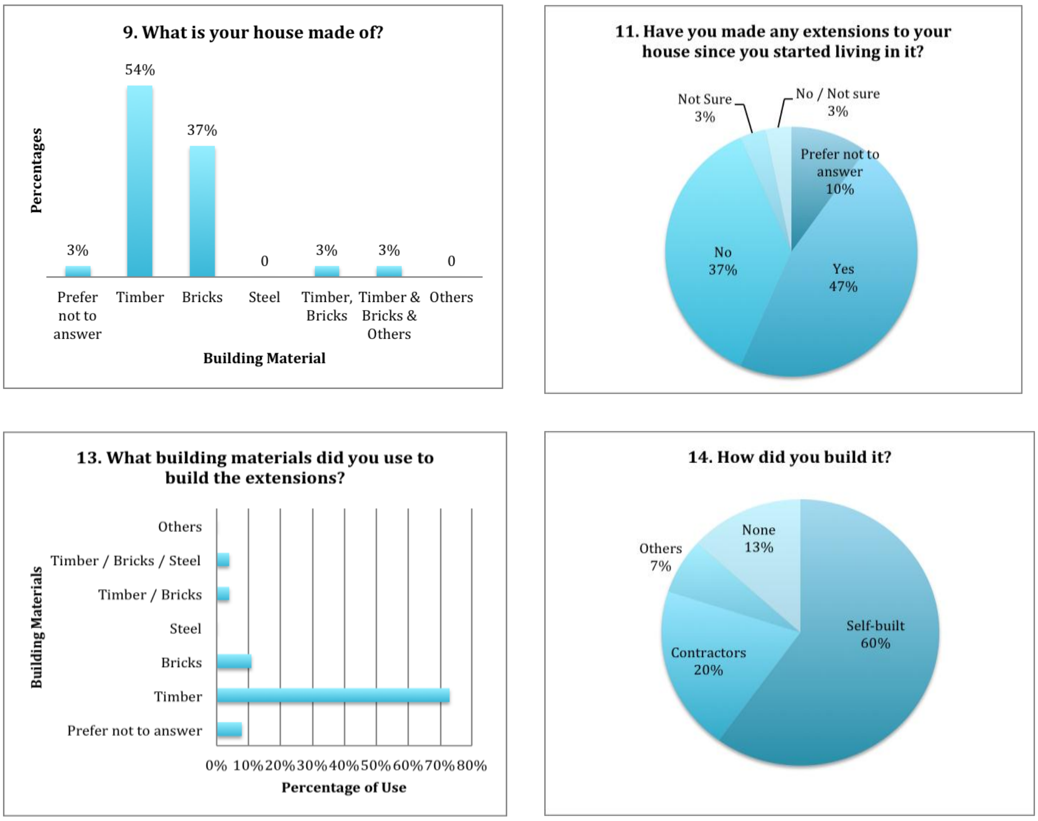

Figure 5: Results of Part: House; Questions 9, 11, 13 and 14.

DISCUSSION ON OBSERVATIONS AND RESULTS OF INVESTIGATION

For houses with larger families, limited sleeping areas and gathering areas leave occupants with the need to utilise other areas of the house for these activities. The living and family TV areas are normally used for sleeping by the older single male members of the family with the priority of occupation of bedrooms given to the married couples and female family members. This indicates a type of hierarchy within the families which is distinctly determined by age, gender and marital status.

It is suggested that the nature of ‘gathering’ has evolved due to the size of the kitchen. Traditionally, the open floor plan of the houses accommodated all household activities. All family members would gather in this open area where they would - together or in their own time - rest, sleep, pray, eat and talk. There was rarely any furniture in these houses and everyone sat on mats/carpets on the floor, which also helped to define space. This was useful during big occasions as they were able to fit large numbers of people in the communal areas of the open interior. In contrast to the set up in the houses today, internal walls and furniture have compromised the previously free-flowing nature of house and reduced its flexibility. While bedrooms are off limits to guests and visitors, all communal parts of the house are used; as such, furniture is often shifted to give an open space. The traditional way of gathering is still favoured and practiced in some houses in Kampong Ayer. The daily family gathering space in traditional open layouts was only ever in one space. In the current layouts the gathering area consists of two spaces; the living area (mainly for receiving guests) and the family TV area (for casual family gatherings). How often the living area was used depended on how frequently they had guests. The family TV area is mainly for watching television, meaning less interaction amongst family members.

From a structural viewpoint, traditional houses in Kampong Ayer, with their open plans and minimal internal partitions, were able to enhance the cooling effect of natural ventilation with the light, constant breeze flowing freely through the houses. Nowadays, the houses, and more so those on land, have evolved into complex layouts with more internal wall partitions. Although this gives more visual privacy within the house, opportunities for efficient natural cross ventilation may be compromised. Renovation of the veranda into another room may have also compromised the advantage of utilising it as a heat buffer. Nonetheless, despite the results from the internal temperature and relative humidity recordings showing that most of the conditions were outside the prescribed thermal comfort range, occupants still managed to feel comfortable with the minimal help of fans/air-conditioning units as a result of using existing passive controls.

With self-building skills becoming less popular in Kampong Ayer, the locals are seeking expertise elsewhere. Not only is this more expensive, but it also means that the ‘sense of community’ that is tied to self-help/self-build is disappearing. This can have a dramatic effect on the sustainability of the water village, as a huge part of their resilience in the past centuries has been through community cooperation. As most of the houses in Kampong Ayer today are originally self-built, its design intent stems from the house owners own desires and necessities. The contents of the houses and the modifications made to the houses over time are clear indications of the constantly changing life stages of each family. The flexibility of the houses in allowing the house extensions and renovations to suit the families’ changing structure has allowed them to remain comfortable in the same houses for many generations (Friedman, 2011).

As has been suggested in numerous other studies, the design of climate responsive houses is often ignored when developing mass-housing proposals and may be dominated by cost, availability of land and population as is common in the aforementioned high-rise typologies. Also, it has been noted that sociocultural issues tend to influence the occupancy and morphology of their houses. It has been suggested that more suitable approach would be to examine both technical and socio-cultural factors side by side so as to derive an approach that would lead to the future development and maintenance of sustainable communities in Brunei Darussalam effectively.

CONCLUSION

Communities usually survive most environmental challenges they face; as long as the adaptability period and means to adapt is within its capability and that there is cooperation amongst the community members to achieve a joint goal to survive. However, some challenges that prove to go beyond the community’s resilience can result in a defeated end. The people living in Kampong Ayer appear to want to continue living there as they have adapted well despite the challenges imposed on the village, such as scarcity of local materials, economics or employment. Their undeniably strong sense of independence and individuality, apparent in the make up of their houses, shows confidence in their spirit to be sustainable. However, the extent of their resilience is yet to be determined. There are certainly other factors influencing the sustainability of such a community, some of these may be future threats. On that note, this paper opens doors to investigate what the limits are to this community’s sustainability in this context.

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Session 5B : Low carbon cities and neighborhood development

PLEA2014: Day 2, Wednesday, December 17
11:30 - 13:10, Compassion - Knowledge Consortium of Gujarat

How effective are ‘close to zero’ carbon new dwellings in reducing actual energy demand: Insights from UK

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ABSTRACT

In the UK, zero carbon will be the standard for new homes from 2016 and non-domestic buildings by 2019. However, it is increasingly recognized new buildings use at least twice the energy predicted by energy models and this gap is relatively poorly understood, thereby risking contravention of zero carbon policy. Yet there is relatively little understanding within policy and wider industry of what might be causing this gap.

This paper investigates the actual energy demand reductions achieved in three ‘close to zero’ carbon social housing developments in UK, through a systematic approach comprising building performance monitoring and post-occupancy evaluation of six case study dwellings over 1.5 years. The six case study houses cover a variety of built forms and different types of construction systems with similar occupancy profiles within the same development.

Findings from the first year of monitoring show that the actual energy use in the case study houses exceeds their design predictions by a factor up to 3. CO_2 footprint across the six houses differ by a factor of nearly 2 in some cases despite all the developments being designed to Code for Sustainable homes level 4 or 5. Consistently high indoor temperatures (>25^{o}C) are observed in the majority of the dwellings both in living rooms and bedrooms. Other issues include lack of user comprehension of mechanical ventilation and heat recovery (MVHR) systems and air source heat pumps, resulting from poor guidance during handover and inadequate commissioning of these systems.

To ensure that such low energy houses perform as intended, seasonal commissioning of services and systems is essential. Occupants need to be trained through graduated handover, supplemented by visual home user guides offering advice on using energy systems and controls. Otherwise there is a risk that UK Government’s zero carbon housing policy may get undermined.

INTRODUCTION

The UK government has passed a legally binding framework to reduce the country’s carbon emissions 80% below 1990 levels by 2050 (UKGBC, 2008). Zero carbon will be the standard for new homes from 2016 and non-domestic buildings by 2019. However, there is a growing concern within the housing industry that, in practice, even current energy efficiency and carbon emissions standards are not being achieved (Gupta and Gregg, 2012). It is increasingly recognized that there is a gap between actual energy use in building and the energy predicted by models (Gupta et al, 2013; Bell et al, 2010). This performance gap may undermine zero carbon housing policy and carry considerable commercial risk for the wider industrial sector (Zero Carbon Hub, 2013). Yet there is relatively little understanding within policy and wider industry of what might be causing this gap.

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Research on the performance gap in the housing sector highlights the need for measuring fabric performance and reviewing the commissioning of services and systems (Wingfield et al, 2011), (Zero Carbon Hub, 2013; Gupta et al, 2013) but also points out the effect of occupant behaviour and understanding (Firth et al, 2008; Steemers and Yun, 2009; Gill et al, 2010).

This paper investigates the performance gap in six case study dwellings across three ‘close to zero’ carbon social housing developments in the UK. A Building Performance Evaluation (BPE) based forensic approach is adopted to evaluate the location and extents of the performance gap for these projects, followed by an in-depth analysis of the empirical findings to reveal the causes of the discrepancies. Findings reveal that fabric performance, installation and commissioning, usability of controls, occupant behaviour and understanding play an important role in influencing housing performance and are the root causes behind the performance gap.

BUILDING PERFORMANCE EVALUATION METHODOLOGY AND CASE STUDIES

Building performance evaluation (BPE) is the process of identifying and locating the gas between ‘as designed’ and ‘in use’ performance through a systematic collection and analysis of qualitative and quantitative information related to energy performance, environmental conditions, fabric performance and occupant feedback. The project is part of the National Building Performance Evaluation (BPE) programme funded by the Technology Strategy Board, the UK Government’s innovation agency. The programme involves both domestic and non-domestic buildings and aims to help the construction industry deliver more efficient and better performing buildings (TSB, 2012).

The six cast study dwellings are part of three exemplar social housing developments (A, B and C) located in South East England). The six case studies (two per development – A1, A2, B1, B2, C1 and C2) were selected to represent a variety of built forms and construction systems with similar occupancy profiles. Table 1 presents the background characteristics of the case studies and Table 2 presents an overview of their design specifications and construction details. Understanding the extent and location of the performance gap in these studies helps to identify ways to address the gap.

Table 1. Case Studies Information

	Development A		Development B		Development C	
Case study reference	Case A1	Case A2	Case B1	Case B2	Case C1	Case C2
Area	94 m²	94 m²	88 m²	123 m²	128 m²	146 m²
Typology	2 bed,mid-terrace	2 bed,mid-terrace	3 bed, end-terrace	4bed, mid-terrace	4 bed, mid-terrace	5bed, detached
Occupancy patterns	24h	24h	15:00-8:00	24h	13:00-8:00	13:00-8:00
Occupants	2 adults, 2 children	2 adults, 2 children	2 adults, 2 children	4 adults, 1 baby	2 adults, 3 children	1 adult, 5 children

Table 2. Design Specifications and Construction Details

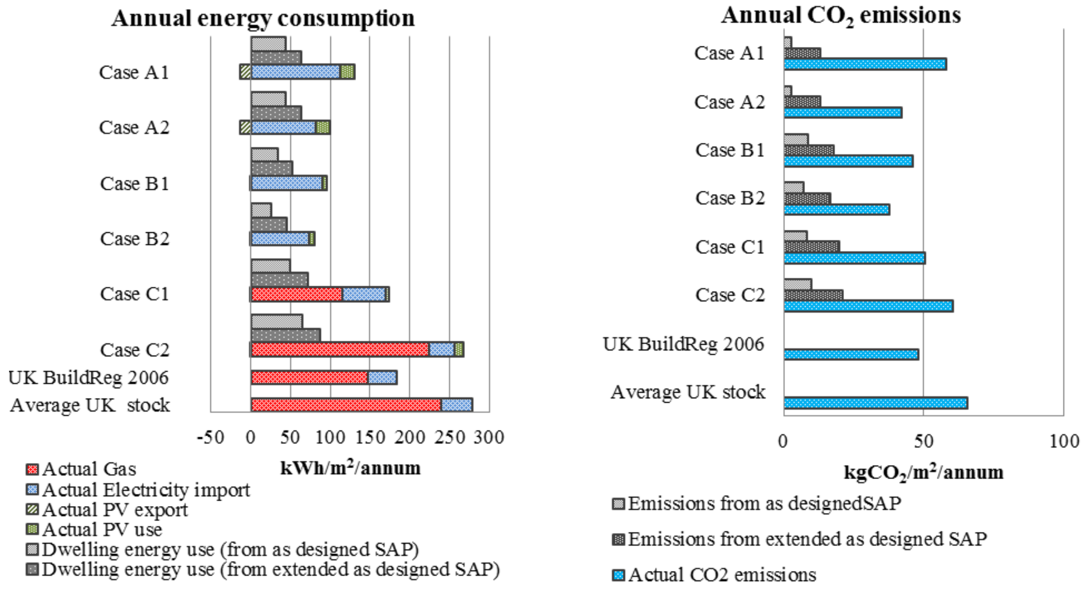
	Development A	Development B	Development C
Construction type	Timber frame with cast hempcrete	Steel frame with pre-insulated panels	Timber frame and brick
Target design rating	CSH Level 5	CSH Level 4	CSH Level 4
As designed U-values W/m²K	Walls 0.18 Windows 1.4	Walls 0.15 Windows ≤1.2	Walls 0.21 Windows 1.3
Space heating and hot water system	Exhaust Air Heat Pump (EAHP), underfloor heating, solar collectors	Air Source Heat Pump (ASHP), underfloor heating, immersion heater back up	Gas condensing boiler with radiators
Ventilation strategy	MVHR through EAHP	MVHR	MVHR
Renewables	4kWpk Photovoltaics	1.5kWpk Photovoltaics	1.65kWp & 1.88kWp Photovoltaics

ACTUAL ENERGY USE

Monitoring data for energy consumption are provided for the period from January to December 2013 as shown in Figure 1. Comparison of actual energy use with 'as designed' SAP[1] predictions reveals big discrepancies between them in all cases. These discrepancies are partly due to the fact that SAP does not cover all end uses of energy in dwellings. To overcome this, SAP predictions were extended to include electricity for lighting and appliances and energy used for cooking. Actual annual energy use exceeds the extended SAP prediction by a factor of 2 in Cases A1, A2, B1 and B2, by a factor of 2.5 in Case C1 and by a factor of 3 in Case C2. Actual annual CO_2 emissions are even higher compared to the extended SAP prediction in all cases. Cases A1 and A2 present the highest discrepancies, exceeding the values of the extended SAP model by a factor of 4.5 and 3 respectively. This is due to the houses being electrically heated.

Cases A1 and A2, although designed for CSH Level 5, consume more electricity than Cases B1 and B2 that have been designed for CSH Level 4. This is partly due to the low COP of the EAHPs in Cases A1 and A2 that has been measured to 1.4 instead of the design specification of 2.6. The design COP of the ASHPs in Cases B1 and B2 is 3.13. Cases C1 and C2 have a similar performance to a typical UK house, despite being designed to CSH Level 4.

There is also significant variation in the energy consumption of houses within the same development designed to the same standard and with similar occupancy patterns (Table 1). In Development A, occupants in Case A2 keep their thermostat at 19^oC and are more energy conscious than their neighbours who keep the thermostat between 25-27^oC. Occupant expectations and control over heating resulted in the annual CO_2 emissions and actual energy use of Case A1 being higher than that of Case A2 by a factor of 1.3. In Development B, annual CO_2 emissions and actual energy use in Case B1 are higher than those of Case B2 by a factor of 1.2 as a result of poor occupant understanding of the ASHP that led to reduction of the system's efficiency. The highest energy consumption is observed in Cases C1 and C2. Annual energy use of Case C2 exceeds that of Case C1 by a factor of 1.5. In both houses occupants set their thermostats as high as 30^oC throughout the day, but in Case C2 occupants tend to leave the windows open day and night even during winter (Figure 4) thus increasing the heat loss and the heating demand.



a) b)

Figure 1 (a) Comparison of actual energy consumption and (b) comparison of actual CO_2 emissions with SAP predictions and Extended SAP prediction across all cases (January – December 2013). Emissions factors: Electricity 0.445 $kgCO_2/kWh$, Gas 0.184 $kgCO_2/kWh$ (Carbon Trust, 2013).

[1] The Standard Assessment Procedure (SAP) is the methodology used by the UK Government to assess and compare the energy and environmental performance of dwellings.

CAUSES OF PERFORMANCE GAP

Fabric performance

The fabric performance of each housing development was forensically assessed using in situ U-value tests, air permeability tests and infrared thermography. The common emerging issues across the three developments are summarized in Table 3.

Table 3. Common emerging issues highlighted by evaluation of fabric performance

	Development A	Development B	Development C
Heat loss through party walls	×	×	
Heat loss through external walls	×		
Heat loss through window and door frames	×	×	×
Thermal bridges (thresholds, ceiling beams)	×	×	×
Actual U-values higher than design	×		
Loft insulation not well distributed		×	×
Actual air-permeability much higher than design	×	×	×

Wall insulation levels were found to be good in all cases. The findings from the in-situ U-value tests showed that in Developments B and C actual wall U-values are similar or even better than those specified at the design stage. However in all cases, thermographic images revealed heat loss and air leakage paths through door and window frames, cold spots in walls and thermal bridges across thresholds. Thermal bridges through ceiling beams and heat loss through party walls were also identified. This has implications for better detailing of joints and juctions by designers and careful implementation by contractors.

Air permeability tests revealed a noteworthy gap between 'as designed' and actual air-tightness in all case studies. All dwellings missed their design target (2-3 $m^3/m^2.h$) with air-permeability in most cases being twice as high as designed as shown in Figure 2. Such high values (5-6 $m^3/m^2.h$) question the actual need for an MVHR system since these have been specified for more airtight homes usually having air permeability below 3 $m^3/m^2.h$. Better air-tightness would have resulted from high quality detailing at key junctions, skirtings and service penetrations and careful workmanship around door and window thresholds and seals.

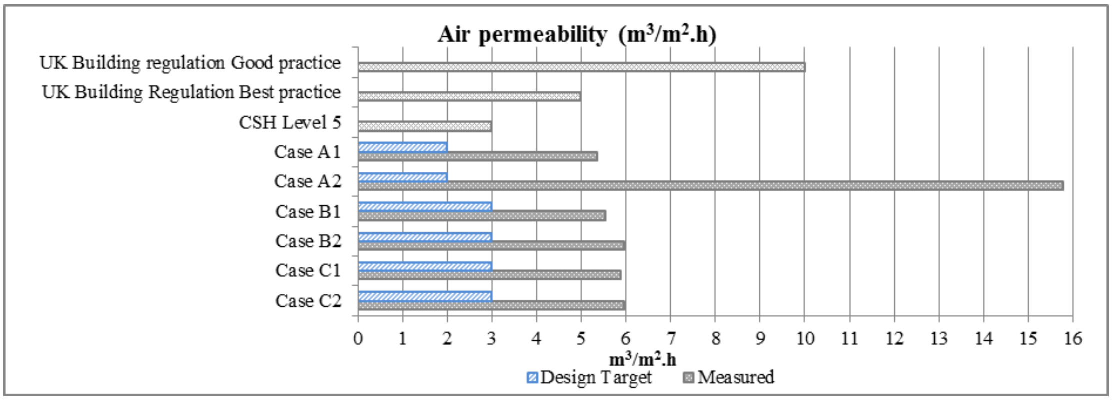


Figure 2 Comparison of measured and design air permeability.

Installation and commissioning of systems and services

A commissioning review is undertaken to ensure that the services and equipment's commissioning are complete and the design and operational strategy was capable of creating the desired performance and comfort.

The MVHR system installation and commissioning was found to be the most problematic issue in all six houses due to the developers' lack of experience with such systems. Improper commissioning and system imbalances were noted in all cases, breakdowns were reported in Cases B1 and B2, noise and cold draughts were reported in Cases C1 and B2 respectively. System imbalance due to poor commissioning and occupant intervention leads to increased heat loss and heating loads, increased energy use of the MVHR unit, system resistance, noise and cold draughts. In some cases (C1, C2) occupants had completely shut the supply terminals thus seriously undermining indoor air quality.

Commissioning of heating controls and room thermostats was also found to be problematic in Developments A and B. In Development A, commissioning check before the move-in revealed that the room thermostats had not been properly connected. In Development B, the wireless room thermostats had not been properly connected to the heating system resulting in the heating being constantly on leading to energy wastage. This was discovered during the study several months after the move-in following occupant complaints of lack of control over heating and of rooms being too hot. Poor commissioning of heating controls results in increased energy use and makes occupants skeptical of the low carbon technologies installed in the houses.

Usability of control interfaces

A review of the control interfaces investigates the relationship between the design and usability of controls and the potential effect they could have during the dwelling's occupancy (Bordass et al, 2007). Table 4 summarizes the key issues that emerged from the three developments.

Table 4. Common emerging issues highlighted by review of control interfaces

	Development A	Development B	Development C
Conflicting control strategies	×	×	
Oversimplified control interfaces	×		
Overcomplicated heating controls and zoning		×	
No indication of MVHR failure or maintenance	×	×	×
MVHR unit inaccessible, located in loft		×	×
Windows and doors intuitive, good fine control		×	×

Heating controls and thermostats were found to be problematic in Developments A and B. In Development B the designers' intention to provide occupants with good levels of control resulted in an excessive use of over-designed thermostats and zones that confuse occupants and complicate commissioning. On the other hand, oversimplified controls like the ones used in Development A, lead to similar results. Unclear, oversimplified or complex control strategies have a negative impact on energy use due to poor occupant understanding and control.

Provision of usable and accessible MVHR controls was an issue for all cases. The MVHR units in Developments B and C are not easily accessible as they are located in narrow loft spaces that hinder maintenance. In most cases, boost buttons do not provide an indication of system response and MVHR units do not give an indication of failure or maintenance. Poor control over ventilation and poor maintenance can lead to increased energy use of the MVHR unit and can also have a negative impact on indoor air quality and occupant comfort.

Handover process and user guidance: communication of design intent

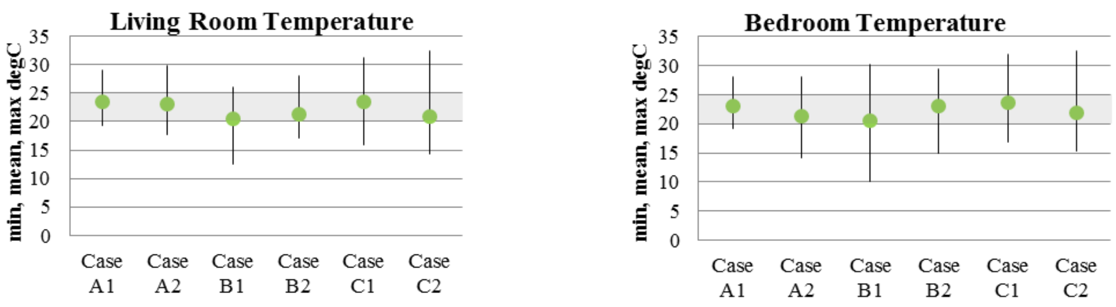
The handover homeowners receive before moving into their new home was observed and the documentation was reviwed to establish whether the information provided is sufficient in communicating the intent and operation of the new home without being overly technical or confusing.

The findings reveal that a phased approach, such as those followed in Developments A and B, is more successful for the handover. However, it would have been more beneficial if the handover also included discussion on the handover documentation (User Guide and O&M manuals) and hands-on application by the occupants. In Development C no phased approach was followed as the handover was completed in a day. Significant risk has been identified regarding the amount of information the occupants can absorb on the day of the handover. The review of Home User Guides showed that the guides generally contain extensive technical details, instead of providing occupants with clear guidelines on how to make better use of systems on a daily and seasonal basis.

Despite the differences in the handover process and guidance documentation, follow up conversation and interviews with occupants revealed that in all three developments some occupants have failed to understand the purpose and operation of the low carbon systems or have forgotten the information that was provided to them initially. Lack of occupant understanding is one of the reasons leading to higher energy use and poor performance of systems. This raises questions about the quality of the handover and the need for retraining the occupants.

Occupant expectations and satisfaction

Occupant behaviour and expectations. Internal temperature data (January – December 2013) reveal that demand temperatures in the houses are high as shown in Figure 3. This is closely related to occupants' high expectations of comfort. Overall temperatures are high with five out of six houses having mean living room temperatures above 21^{o}C and three out of six houses having a mean above 23^{o}C. Peak temperatures above 27^{o}C were also observed in the majority of the houses (five out of six). Bedroom temperatures present a similar trend with five out of six houses having mean bedroom temperatures above 21^{o}C. Cases A1 and C1 have the highest mean temperatures as the occupants use a lot of heating energy by keeping their thermostats around 25-27^{o}C throughout the day. In Case C2 occupants also keep their thermostat very high throughout the day (30^{o}C) but mean temperatures are around 21^{o}C because occupants keep their windows open for many hours during the day (Figure 4), thus leading to the high gas consumption shown in Figure 1. This level of demand is leading to a gap between design prediction and actual consumption in terms of both energy use and environmental conditions.



a) b)

Figure 3 Mean, minimum and maximum temperatures in (a) living rooms and (b) bedrooms (January – December 2013).

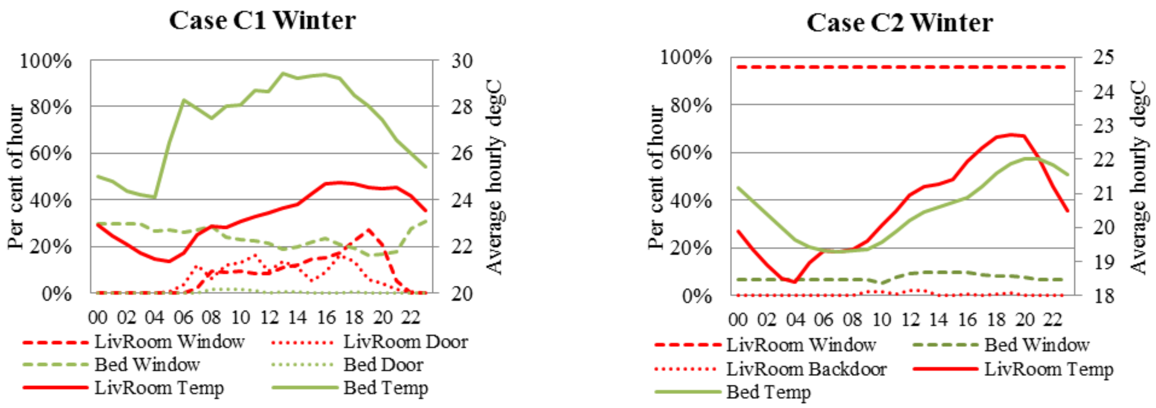


Figure 4 Hourly average temperatures and hourly percentage of window opening across a day (November – April) in Case C1 and Case C2.

Occupant surveys, interviews and walkthroughs. Occupant satisfaction surveys were carried out in all three developments using standardized occupant satisfaction questionnaires (BUS). Additionally, semi-structured interviews and walkthroughs were carried out with the occupants of the six case studies using the same templates. Table 5 summarizes the positive and negative occupant feedback from the survey and occupant interviews related to contols, comfort and satisfaction with space.

Table 5. Common emerging issues highlighted by occupant survey and interviews.

	Development A	Development B	Development C
Positive feedback			
Satisfaction with space and layout	×	×	×
Satisfaction with design and appearance	×	×	×
Satisfaction with light levels (natural, artificial)	×		×
Temperatures good overall	×	×	×
Negative feedback			
Poor control over heating	×	×	
Lack of understanding of heating system	×	×	
Lack of knowledge about MVHR	×	×	×
Poor control over ventilation		×	
Hot during summer		×	
Home User Guide considered complicated.	×	×	
Energy bills considered high	×	×	×

In all developments occupants are fairly satisfied with the appearance, design, layout and space of the houses. Also, daylight levels are appreciated in most cases. Most negative feedback involves the operation and control of the heating and MVHR system. Control over heating is considered problematic in Developments A and B that feature heat pumps and underfloor heating as occupants are not well familiar with such technologies and find the Home User Guide confusing. Control over ventilation is also considered problematic in most cases due to occupant confusion about the operation of the MVHR system. Moreover, energy bills are high in all houses althought all three developments designed to reduce energy use. Occupants in Developments A and B are very unhappy with their electricity bills which they attribute to the poor performance of the heating system. In Table 6 actual electricity and gas bills are between 3 to 20 times higher than the SAP estimated energy costs.. The combination of many new technologies, unfamiliar to both the occupants and the developers and owners, led to confusion and dissatisfaction in most cases.

Energy use in houses depends heavily on the occupants' perception of comfort and their attempts to attain comfortable conditions. Thermal comfort satisfaction is closely linked to the level of understanding and control over the heating and ventilation system. Resolving the issue of comfort and control effectively and understanding occupant expectations through follow-ups and training are essential for closing the performance gap and achieving better environmental conditions.

Table 6. Comparison of actual bills with SAP estimated costs and UK typical domestic energy bills

Cost (£)	A1	A2	B1	B2	C1	C2	UK typical [2]
Predicted (SAP) cost	70	70	330	336	259	315	
Electricity bills	1,440	1,200	1,300	1,100	700	960	424
Gas bills	-	-	-	-	720	1,500	608
Actual total cost	1,440	1,200	1,300	1,100	1,420	2,460	1,032

CONCLUSION

Using a mixed-methods socio-technical BPE approach, this study has identified the reasons for underperformance of 'close to zero' carbon new dwellings. The study has revealed that the actual energy use in the case study houses exceeds design predictions by a factor up to 3. Furthermore, actual energy use across the six case study houses varies by a factor 1.6, despite all the developments being designed to CSH Level 4 or 5 and having similar occupancy profiles. Fabric performance, commissioning of systems, usability of controls and occupant understanding and expectations increase the gap between actual and design performance. Discrepancies in fabric and system performance may result from difficulty of communicating design intentions and expectations, specification error or omissions and construction errors. Such issues could be avoided through rapid diagnostics onsite and better

[2] Typical UK domestic energy bills and consumption figures based on average household bills (Ofgem, 2011)

communication between all stakeholders. Installation and commissioning is clearly an area where increased training and awareness and checks will have a large impact on improving the performance of dwellings. In order to improve commissioning and maintenance developers and constructors need to ensure that their technicians receive adequate training. Seasonal commissioning also needs to be encouraged for houses with technologies such as heat pumps and MVHR systems.

The study also highlights the need for a detailed and coordinated services layout plan showing location of systems and controls that will help to solve issues of accessibility and will provide the basis for a clear strategy that the occupants need to follow. Combination of clear design intentions, intuitive and responsive control mechanisms and good occupant guidance and training will ensure better use of systems and increase the potential for energy reductions and improvement of environmental conditions. Findings indicate the need for graduated handover that involves hands on application by occupants, supplemented by visual home user guides offering clear guidance on the daily and seasonal operation of systems and controls. Guidance must be customized according to residents' background and abilities.

Learning from real-world case studies is an insightful way for understanding the reasons behind the energy performance gap in order to achieve low carbon housing in practice. This requires a formalized briefing, commissioning and feedback protocol, such as 'Soft Landings' (BSRIA, 2009), that has started to be used in domestic projects. This will help to ensure that these lessons are captured and fed back to the developers, constructors and designers. Otherwise there is a risk that UK Government's zero carbon housing policy may get undermined.

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A quiet revolution: Mapping energy use in low carbon communities

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ABSTRACT

Recent Government funding in the UK has enabled 22 low carbon community organisations to work with the private and academic sector to understand and reduce energy consumption in domestic and non-domestic buildings. This has helped communities prepare for policy mechanisms such as the national Green Deal programme which aims to improve existing housing and non-domestic buildings by offering up-front loans to be repaid by energy savings. This paper presents the role and application of a unique carbon mapping approach, which has enabled five of these low carbon communities to rapidly assess on a house-by-house level, the potential for improving the energy efficiency of their housing stock. DECoRuM, an award-winning GIS-based carbon counting model is used to measure, model, map and manage energy use and CO_2 emission reductions from approximately 1,300 houses across five communities, displaying estimates of energy use and carbon emissions before and after community action. Incremental packages of energy saving measures and low carbon technologies are assessed for their impact on CO_2 emissions to reveal further potential for large-scale refurbishment in the local area. Eligibility for the Green Deal is tested to show that on average 72 per cent of homes over all communities are suitable for finance. Through community events, results are visualised and fed back to the householders using colour-coded spatial maps along with thermal imaging. Findings from this study are relevant for policy-making and practitioners engaged in area-based carbon reductions.

INTRODUCTION

The UK is committed to reducing greenhouse gas (GHG) emissions by 80% from 1990 levels. In response to this commitment, the national Green Deal programme has been proposed to offer energy efficiency improvements to homeowners and businesses at little or no upfront cost with payment recouped through customers' energy bills (DECC, 2012a). The Energy Company Obligation (ECO), proposed to work alongside the Green Deal, will similarly support those experiencing fuel poverty and in hard to treat homes. In addition to the Green Deal, recent Government funding in the UK has enabled 22 low carbon community organisations to work with the private and academic sector to understand and reduce the amount of energy that is used in homes and buildings. One such programme, the Low Carbon Communities Challenge (LCCC), focussed on stimulating energy improvements of homes through capital funding of physical interventions to homes and buildings, behaviour change campaigns and low carbon living activities. The theoretical savings from the 8,206 installed measures and technologies for the entire programme is 3,062 tonnes of CO_2/yr (DECC, 2012b).

The Department of Energy and Climate Change (DECC) (2012b) provide an overall qualitative review of the LCCC impact. Gupta *et al.* (2014) applied a measurement, monitoring and evaluation (MME) approach to 88 households across six LCCC communities. Their findings show mixed results in

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terms of energy use across the households depending on a number of factors including the physical and technical interventions, and occupant behaviours and lifestyle. The detailed evaluations also uncovered unintended consequences associated with energy behaviours, such as increased use of washing machines and other such appliances due to 'free electricity' from low/ zero carbon technologies.

Geographical information systems (GIS) provide a platform for presenting findings in an aggregated form which can be visually effective in communicating results to householders and community groups. A number of GIS based studies focus on energy use estimations using a top-down approach. These include using remotely sensed anthropogenic heat to serve as a proxy to derive the spatial pattern of energy use (Zhou et al., 2012) or combining location, demographic and end-use data to enable energy consumption to be calculated and mapped (Pereira and Assis, 2013). In contrast to the above, the present study combines a bottom-up building characteristic data collection approach to estimate energy use and carbon emissions of approximately 1,300 dwellings over five communities, Community A, B, C, and D (anonymised as per communities' request) in England and Wales, combined with a top-down approach to analysis and geographical visualisation. This is demonstrated through the application of urban energy modelling using DECoRuM© (Domestic Energy, Carbon counting and carbon Reduction Model), to rapidly model, map, and measure energy use and carbon emissions on a house-by-house level. The following method calculates the carbon reduction impact of the LCCC and the impact of further carbon reduction measures for the five communities. The work presented in this paper is part of the Evaluating Low Carbon Communities (EVALOC) project which seeks to assess, explain and communicate the changes in energy use due to community activities within selected case study projects under DECC's LCCC initiative.

METHODOLOGY

The following steps are taken to map and assess the energy consumption, carbon emissions, and retrofit potential for the selected communities:

1. Data collection (e.g. home details, local climate data, etc.), modelling and mapping in GIS
2. Assessment of results, e.g., carbon emissions, before the LCCC and after the LCCC
3. Selected carbon reduction / Green Deal packages are applied to the neighbourhood and the results are calculated and mapped

The communities

Table 1 lists the five communities and some further details.

Community	Number of Households	Dominant Built Form
A	311	1930-49 semi-detached
B	242	1966-76 terraced
C	274	Pre-1900s terraced
D	184	Pre-1900s terraced
E	275	Pre-1930s terraced

DECoRuM model

DECoRuM is a GIS-based toolkit for carbon emissions reduction planning with the capability to estimate energy-related CO_2 emissions and effectiveness of mitigation strategies in existing UK dwellings, aggregating the results to a street, district and city level. The aggregated method of calculation and map-based presentation allows the results to be scaled-up for larger application and assessment. The background calculations of DECoRuM are performed by BREDEM-12 (Building Research Establishment's Domestic Energy Model) and SAP 2009 (Standard Assessment Procedure) both of which are dynamically linked to create the model. BREDEM is a methodology for calculation of the energy use of dwellings based on characteristics; it is suitable for stock modelling. It shares some features with the SAP methodology, but allows users to adjust inputs which are fixed in SAP (BRE, 2014). SAP, based on BREDEM is the Government approved method for the assessment of the energy and environmental performance of dwellings. Though not as robust as dynamic thermal simulation, the strength of DECoRuM is in the ability to rapidly process results for many dwellings and present them on an urban scale. The tool is useful for communicating energy related concepts and identifying potential areas for concern and further investigation, including simulation, house assessment and monitoring.

Some limitations include:

- Time required for data collection and entry; home questionnaires are helpful in reducing this initial effort.
- Behaviour related assessment is limited: occupancy times, heating schedules, window opening schedules, etc. are not available. Different scenarios must be calculated separately and cannot vary within a given timeframe; calculations are static.
- The model does not calculate where specifically a homeowner should insulate walls and whether internal or external insulation is ideal (insulation is simply either solid wall or cavity).

Data collection and modelling. In the DECoRuM model, CO_2 emissions are the result of heat loss calculations from fabric and ventilation, estimated energy use from heating, domestic hot water and electricity use as calculated using BREDEM-12. To inform the model, actual house characteristics are gathered from historic and current maps, on-site assessment, home occupant questionnaires, Energy Performance Certificates (EPCs), and literature describing home characteristics based on age and typology. As examples: occupancy, unless known, is calculated from floor area using the BREDEM-12 method; street-facing windows and frames are directly observed but all other unseen windows are assumed to be the same; wall construction and U-values (unless known, e.g. reported in EPCs) are based on the age of the home where construction methods are well documented (e.g. BREDEM reference tables). Verification is performed by calibrating the aggregated results to DECC's *lower level super output area* (LSOA) energy consumption data for England and Wales. LSOAs are zones made up of an average of 1500 residents or 400 households with relative social homogeneity, for which there are gas and electricity consumption figures reported (DECC, 2014a). Use of LSOA data for a similar purpose can be found in Booth and Choudhary (2011) and Williams *et al*. (2013).

Mapping the results. The results for each household are displayed on a map using GIS software; in this instance MapInfo. GIS allows any variable to be mapped for visual communication, e.g. kWh/year, CO_2 emissions/m^2/year, homes in need of cavity wall insulation, PV suitability, etc. Previously, DECoRuM maps have been used by the Grassroots Leads Energy Efficiency community group in Highfield, Bicester to provide residents with energy consumption information and to suggest energy efficiency improvement measures (Gupta and Cherian, 2013), and to present climate change impact and adaptation effectiveness to communities in the SNACC project (Suburban Neighbourhood Adaptation for a Changing Climate (Williams, *et al.*, 2013).

Carbon reduction measures. Previous research by the authors and others has demonstrated the development of mitigation measures and packages, which were found to be effective for similar home typologies (Gupta and Gregg, 2012; DECC, 2014b). This and other research (simulation and building performance evaluation) have demonstrated the effectiveness of specific mitigation measures for CO_2 reduction in homes. These include reduced U-values on building elements, high efficiency boilers, insulating hot water cylinder and pipes, and increased level of heating control. When creating packages, focus on a fabric based package is done to emphasise the importance of implementing fabric first (low tech demand reduction) measures and also due to its (generally) lower capital cost.

MAPPING LOW CARBON COMMUNITIES

Each of the 22 communities, as a part of the LCCC, received grants ranging from £250k - £970k to pay for physical interventions to homes and buildings (90%) and behaviour change activities (10%) (DECC, 2012b). **Table 2** lists the physical measures purchased for households against those which were mapped in DECoRuM. Community scale measures or non-domestic measures, e.g. wind turbines (Communities A and B), PV on community centres and schools (Communities D and E), are not listed because the contribution of these measures are not calculated in the household (demand side) energy consumption modelling of DECoRuM; in addition, LSOA, used to validate DECoRuM, only provides consumption values. With regard to household measures, not all households in the communities received physical measures and not all households that did receive measures are mapped. The impact of behaviour change will likely indirectly come out of the aggregated figure as the aggregated figure is validated by the LSOA, however, the MME method used in Gupta and Barnfield (2013) is essential for measuring the impact of behaviour change activities in detail.

Table 2. Physical Measures Applied to Households in Each Community (DECC, 2012b)

Community	LCCC measures (total households)	Measures (mapped)
A	(0)	PV (9), solar thermal (2) ASHP (2)
B	Cavity wall insulation (125), loft insulation (223), PV (12), solar thermal (6), ASHP (4)	Cavity wall insulation (10), loft insulation (28), PV (3), solar thermal (1)
C	PV (11), solar thermal (4), wood pellet boiler, ASHP (3)	PV (6), solar thermal (4), ASHP (3)
D	PV (53)	PV (53)
E	PV (8)	PV (4), solar thermal (1)

Communities before LCCC action

Occupant questionnaires (requesting specifically when measures were installed), EPCs (pre-2010) and LCCC household details were especially helpful in modelling the communities before LCCC implementation. Though occupant questionnaires or EPCs were not available for each household, these tools served to inform the model with regard to what measures did not exist in many households before the LCCC. Since measures were purchased and installed anywhere from 2010 – 2012, the maps of Pre-LCCC implementation are referred to as *Pre-2010*.

Communities after LCCC action

In the same way, the same tools were used to assess what measures are in place after LCCC implementation. These maps are referred to as *2012*. **Figure 1** shows the Pre-2010 and 2012 results from Community E. *After* the interventions made by LCCC programme in Community E, there is a mean annual CO_2 reduction of 536 $kgCO_2$/yr/household or 12 per cent in the mapped area in 2012. These results can be attributed to LCCC involvement, but not entirely, as not all mapped households were involved in the LCCC.

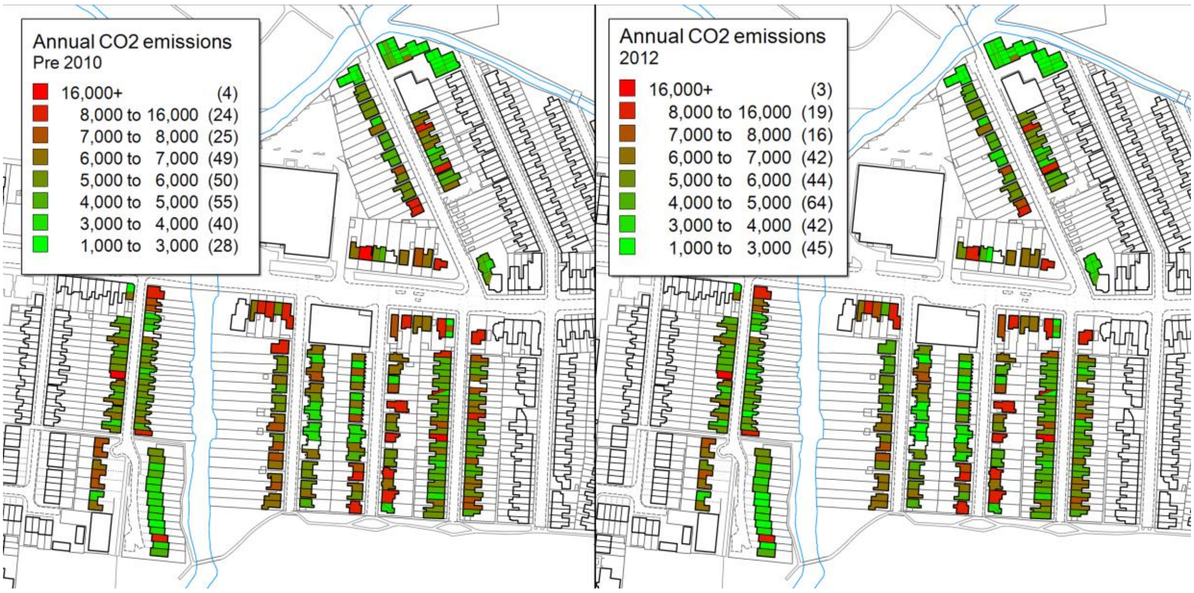

Figure 1 Pre-2010 and 2012 maps of annual CO_2 emissions for Community E.

Table 3 lists the communities and the results from the mapping for these two periods. Aside from other differing factors, Communities A and C are not served by the National Gas Network and are notably higher in annual emissions due to a majority of occupants utilising oil or electricity for heat.

Table 3. Mean annual domestic CO_2 emissions ($kgCO_2$/year) before and after LCCC programme

Community	Pre-2010	2012	2012 City Mean
A	5,969	5,286	Not available
B	4,564	4,046	4,179
C	9,298	7,111	Not available
D	5,753	4,889	4,895
E	4,574	4,038	4,454

Carbon reduction measures and packages

The model filters suitable dwellings for each retrofit measure based on the current (2012) condition of the dwelling, e.g. solid walled homes receive solid wall insulation and insulated cavity walls received no further insulation. Potential energy and carbon reductions are then calculated by the model for each household and then aggregated to realise community level impact. To meet the Government's carbon reduction target, most UK homes will require a package of measures (DECC, 2014b); therefore, the following typical retrofit measures were tested individually and also incrementally packaged. **Table 4** lists the packages that were developed for testing in DECoRuM; all measures are acceptable for Green Deal financing. Lowering the thermostat, a behaviour change measure, was also tested and presented to residents but not packaged. Primarily, the reason for this is that the packages were designed to reflect measures with capital costs so that the packages could be tested for Green Deal finance suitability.

Table 4. Carbon Reduction Packages

Package	Measures
Fabric improvement package	Wall insulation (cavity or solid), loft insulation, floor insulation, double glazing, draught proofing
Fabric and heating upgrade package	**Fabric package** + high efficiency condensing boiler, hot water cylinder insulation, pipework insulation, heating controls
Fabric, heating and electricity package	**Fabric and heating upgrade package** + energy efficient lighting and appliances, photovoltaic system, solar hot water system

An important key driver for refurbishment is capital cost. DECoRuM uses low and high estimates of the capital costs for each measure to indicate a likely range for the cost-effective carbon saving potential (the mean is taken from these two figures). The overall capital cost for community wide implementation of a certain package is calculated, based on the potential of each house within the community. **Figure 2** shows the mean capital costs and energy cost reduction potential for each package in the two most common house types in Community E. The Pre-1930s terraced housing represents 28 per cent of the dwellings in the mapped area and 1930-1949 semi-detached represents 18 per cent.

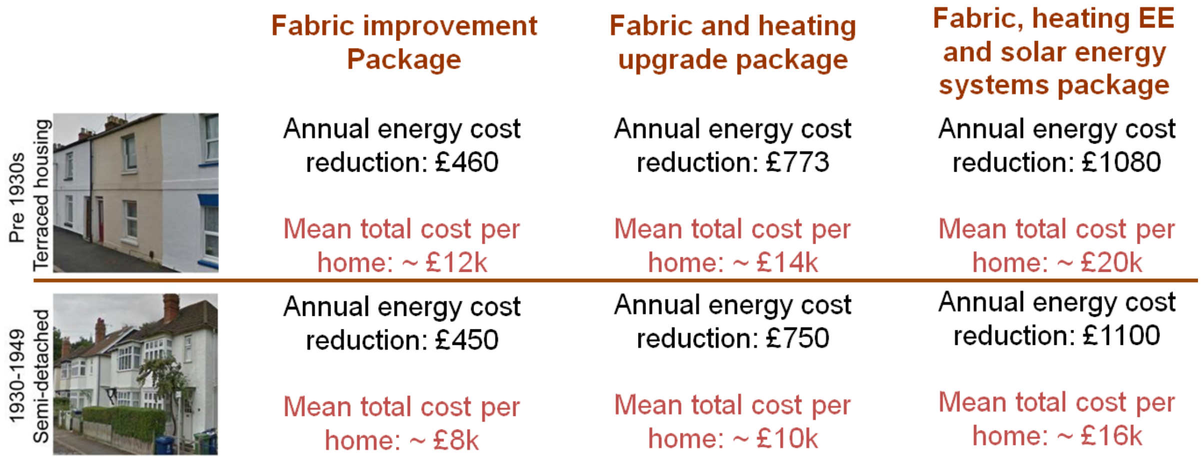

Figure 2 Package capital costs and reductions for Pre-1930s and 1930-49 house types in Community E.

The mean total cost for each home only considers those dwellings which could benefit from a measure in each package, though not all measures in the package need to be applied to qualify for the package in the model. Immediately as is seen in figure 2, Pre-1930s cost more to retrofit. This is attributed to the solid wall exterior of the house type, which will require solid wall insulation. The cost for solid wall insulation for each home is taken from the mean of external and internal insulation. Due to the nature of the data collection, especially where no questionnaires are filled, the model does not have the capability to assess whether internal or external insulation is a better choice for a particular dwelling. Annual cost reductions are a combination of a reduction in fuel costs and feed-in tariff (FiT) and Renewable Heat Incentive (RHI) (paid from April 2014) payments for PV and solar hot water respectively. Differing FiT payments, as per EPC grade, per house, are calculated into the total figure.

Carbon reduction packages and the Green Deal

Each carbon reduction package is then tested for Green Deal finance (theoretical) approval, specifically; will each package meet the *Golden Rule* on a house-by-house level? The Golden Rule is the central mechanism for determining which measures (to complete a package) are able to be financed through the Green Deal. The rule: “Estimated savings must be greater than or equal to repayments.” This, however, is not a guarantee but a calculated intent (DECC, 2012).

DECoRuM has the capability to calculate whether a package will meet the Golden Rule after measures are modelled and energy use reduction and energy cost reductions are calculated. The model calculates whether the annual fuel cost savings are less than the annual payback over the life of the measure(s). **Figure 3** shows the Golden Rule compliance for each package for Community E. As an example, a large portion of the terraced housing in the southeast section of the Fabric Package map do not meet the Golden Rule primarily because the cost of solid wall insulation and new double glazing together is too high in relation to the potential savings. In order to qualify some dwellings will need to consider alternative combinations of measures. It is also important to point out that the cost for solid wall insulation, as mentioned above, is an average fixed cost between external and internal wall insulation; opting for internal wall insulation would likely reduce the capital cost for the overall package. Alternatively, the strip of homes in the northeast section of the Fabric Package map (next to the legend) meets the Golden Rule. Most of these dwellings are 1930-49 semi-detached (**figure 2**) requiring cavity wall insulation, a less expensive measure.

Figure 3 Golden Rule compliance for each package in Community E.

DECoRuM modelling demonstrated a fairly wide range of Golden Rule compliance between the communities (**table 5** – the packages are numbered in the order they are listed in **table 4**). Communities A, B and C, as communities, appear to be easier targets for the Green Deal. Communities A and C specifically have more reduction potential, partially due to the size of the dwellings and the majority using oil for heating. Community B, on the other hand, for the Fabric Package, requires little up-front cost whereas all homes are cavity wall (many already insulated – table 2) and many already have double glazing (the second most costly fabric measure following solid wall insulation). Community D, comprised of 94 per cent solid wall terraced housing, presents a challenge in meeting the Golden Rule for the Fabric Package. Package 3 clearly becomes more difficult due to the cost of PV and solar hot water systems (poor solar orientation is also calculated into the reduction in solar systems impact). FiT and RHI payments do not count toward reduction of savings to calculate the Golden Rule. A dwelling could use the Green Deal finance to install PV and collect the FiT but if a home is performing poorly according to their EPC, e.g. worse than D, their FiT is reduced, thereby encouraging fabric improvement first (or in conjunction). The Green Deal also only covers a portion of the capital cost for PV depending on how much electricity is actually (calculated) used in the dwelling.

Table 5. Percentage of Homes in Each Community Satisfying the Golden Rule (per Package)

Community	Package 1	Package 2	Package 3
A	91%	91%	65%
B	100%	87%	13%
C	84%	79%	64%
D	29%	27%	11%
E	54%	48%	31%

DISCUSSION

Outputs from DECoRuM, maps of estimated energy use and CO_2 reduction potential of individual households, were used to provide energy feedback to householders (on a community level) through workshops, wherein the local community also had access to expert information and advice on taking action to reduce energy use through individual discussions and group presentations. The maps, along with thermal imaging surveys of the houses, used to make energy use visible by highlighting areas of heat loss and potential areas for fabric improvements, gave householders a clear view of the impacts different refurbishment measures and packages have had or may have on the energy performance of their house. The workshops also helped to gather more data from householders (using questionnaires), to further refine the model.

The communities are using the findings from the carbon mapping, along with thermal imaging and the MME studies to inform the householders in the community on effectiveness of work already done and also highlight areas for improvement. The carbon mapping is specifically useful for the community groups to pinpoint areas of high energy use, problem households and promising areas for Green Deal finance. The application of packages, the calculated impact, and costs, as shown through carbon mapping, establishes DECoRuM as a useful tool for Green Deal assessors, local authorities and the low carbon community groups intending to implement large scale retrofits.

It is important to remember that there are many combinations of carbon reduction measures and they do not need to follow the packages as defined in this study. It is likely that many more homes will be able to find a package that will fit their home and meet the Golden Rule. There are also a large number of ‘border line’ cases (houses which almost meet the Golden Rule). This highlights the importance of adopting a holistic approach that includes both technical improvements and behaviour change measures; one which the Green Deal is attempting to provide through energy saving advice (DECC, 2012a). This approach, where effective, would ensure that most of the predicted energy savings are achieved in practice and the Golden Rule will be met.

CONCLUSION

Carbon mapping has emerged as a valuable approach for strategic planning, evaluation and implementation of community and neighbourhood scale domestic refurbishments by rapidly measuring, modelling, and mapping and managing energy use and CO_2 emission reductions on a house-by-house level. Bespoke site specific mapping of current energy consumption and visualisation of the potential for energy savings can enable the uptake of carbon reduction measures. The model can help local authorities, community groups and householders to prepare for future change and policy mechanisms such as the national Green Deal programme and the ECO. The specific area-based approach can serve as a tool to scale-up the uptake of low energy domestic refurbishments, by providing Green Deal providers, local authorities, community organisations and householders with information on the technical and economic feasibility of deploying a suite of best practice refurbishment measures. Findings from this study are also relevant for practitioners and researchers engaged in tracking and assessing impact of large-scale area-based domestic refurbishments and the future effectiveness of the Green Deal after implementation.

Similar work includes the development of DECoRuM-Adapt, a next step for DECoRuM created to assess future climate impact, overheating risk and adaptation measure effectiveness. The assessment of the climate change risk allows for the further evaluation of mitigation measures to optimise the home's refurbishment to be thermally comfortable now and in the future (Gupta and Gregg, 2013). To further benefit research in this area, future work in urban modelling would include analysis of modelling outputs with socio-economic data to track the effect of refurbishments on fuel poverty.

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The Impact of Vegetation on Urban Microclimate to Counterbalance Built Density in a Subtropical Changing Climate

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ABSTR ACT

The purpose of this paper is to assess the cooling effects of vegetation in urban microclimate, especially during daytime, to counterbalance built density in a subtropical climate. The findings contribute to a land-based mitigation strategy, trying to answer partially what a changing climate will mean for cities facing two mechanisms that can be superimposed: the global warming and the local heat-island effect, in the city os Sao Paulo, Brazil. According to the Brazilian Panel on Climate Change (PBMC), Brazil's climate will be warmer in the coming decades, with a temperature increase in all regions between 1ºC and 6º C by 2100, compared to the records at the end of the 20th century. The paper presents a brief review of planning with high-density and urban greening, having in mind that even low-density land use can contribute to urban heating, depending on the infrastructure development. In high-density cities, the most important vegetation effect is to prevent overheating in urban canyons, decreasing solar radiation absorption by shading and increasing evaporative cooling by the leaves and soil coverage. This way vegetation prevents overheating of buildings and other urban surfaces, contributing to better comfort conditions. Parametric studies exploring different scenarios of high-density urban blocks and greening have been carried out to investigate two different distribution of dense trees (LAI=4,6) to ameliorate urban microclimate using ENVI-met model 4 (preview), previously calibrated with field measurements of local climate and vegetation data. Aiming to benefit urban activities, air and mean radiant temperatures at the pedestrian level are compared. None of these will reverse long-term warming trends but, as we move from mitigation to adaptation, combinations of these strategies can slow the pace of warming over time and moderate urban warming, indicating a way forward for urban design in tropical and subtropical cities.

INTRODUCTION

Brazil has recently constituted the Brazilian Panel on Climate Change (PBMC). According to PBMC (2013), Brazil's climate will be warmer in the coming decades, with gradual and variable average temperature increase in all regions between 1ºC and 6ºC by 2100, compared to that recorded at the end of the 20th century. Brazil has its own voluntary commitments for emission reductions, as part of the National Politics for Climate Change, but adaptation measures for urban areas are still missing, and some local research groups are investigating this, aiming to support the review of the National Plan for Climate Change. Land use as a climate change mitigation measure, especially in urban areas, is underexplored; in this scenario we need more resilient cities and, for that, adaptation is crucial.

THE URBAN CLIMATE AND THE COUPLING OF GLOBAL AND LOCAL EFFECTS

Concerning the coupling of global and local warming effects, cities do not cause heat waves, but they amplify them. Because of the greater prevalence of mineral-based building materials, cities absorb and retain substantially more heat than rural areas characterized by more vegetative cover. Because of that the main reason for city warming is not the global warming itself, but the replacement of the vegetation for hard surfaces and the anthropogenic emissions (Stone, 2012).

One of the climate related land use implications is the urban heat island (UHI), which is more diverse than originally suspected (Arnfield, 2003). On the surface UHI is easy to understand and to visualize the results of urbanization. However, UHI is a multi-faceted phenomenon whose proper definition and physical basis is more complex. Proper understanding of the definition and types, dynamics and underlying physical processes of the UHI, however, is key to formulating mitigation measures (Roth, 2013). Besides differences based on the medium sensed (air, surface, even subsurface) and the sensing system employed (Arnfield, 2003), there is growing evidence supporting the existence of phase and amplitude departures in the UHI in tropical cities, in comparison with mid-latitude cities (Marques Filho *et al*., 2009; Chow; Roth, 2006). The UHI in tropical and subtropical cities is less intense than in higher latitude cities, and it is more pronounced during daytime and strongly regulated by the moisture content of the atmosphere and soil in adjacent rural regions (Roth, 2007). As well as in other tropical and subtropical climates, according to Ferreira *et al.* (2012), the UHI in the city of São Paulo has a daytime character, with a maximum intensity during afternoon (14:00-16:00 LT) and a minimum during morning time (07:00-08:00 LT) in almost all months monitored in 2004. The maximum UHI intensity varied from 2.6ºC in July (16:00 LT) to 5.5ºC in September (15:00 LT).

The role of density

Cities differ from their rural surroundings in a multitude of ways, many of them directly related to the surface energy balance and the formation of UHIs. Urban form is affected first and foremost by building dimensions and spacing, but also by the characteristics of artificial surfaces and by the amount of green space. The presence of a dense matrix of buildings promotes the creation of UHIs through a variety of processes, for example, the trapping of solar energy due to multiple reflection and absorption within canyons, the restricted sky view factor of deep and/or narrow canyons and reduction of wind speeds near the ground (Erell *et al*, 2011).

For several reasons, one of the current needs of urban settlements is a higher urban density, a topic that still causes some debate, but from mobility and urban climate points of view, low-density areas can be even worse. According to Stone (2012), areas of low population density may still effect a significant influence on UHI formation if they have extensive infrastructure development.

The urban climatic issues of heat, humidity, lack of daylight, solar access and urban ventilation is of topical concern to urban planners and governments, so, the need for appropriate designs for high-density cities is clear. Urbanization and higher-density living is an irreversible path of human development. Higher-density living will continue to be developed and will soon be the norm. The environmental dimensions of high-density cities, especially in tropical and subtropical climatic zones, are decisive. Buildings are fighting each other for natural light and ventilation. The provision of light and air can be difficult; a paradigm shift is required, new tools are needed, but high-density living is a definite possibility, although it is not an easy path (Ng, 2010). To increase ventilation, height variation should be considered as much as possible; the stepped height concept can help to optimize the wind-capturing potential as well as the view of sky component for daylight availability. Designed properly, the strategy of tall and thin has a better chance to capture daylight. Given the same building bulk, on average, daylight availability to windows can improve by some 40 per cent (Ng; Wong, 2005).

The role of Green

Planted areas in a city tend to reduce daytime maximum temperatures, reducing radiant exchange at the ground surface. The effect of vegetation on the atmospheric heat island is manifested not only indirectly, in the form of a reduction of sensible heat flux from the cooler surface, but also directly in the form of evaporative cooling. Most field studies support the argument that a lack of vegetation in the city would tend to result in elevated daytime air temperature, and concomitantly, that a large-scale planting campaign may lead to a reduction of the daytime urban heat island (Erell *et al*., 2011).

According to Chen and Wong (2010), in a built environment the UHI effect can be described as a conflict between buildings and the urban climate, and considering the positive impact of plants upon this conflict, a conceptual model was proposed by the authors to understand the interactions among the three critical components in the built environment: climate, buildings and plants. In order to uncover the benefits of greenery in a built environment, the microclimatic effects should be quantified. There are some possibilities to reduce ambient air temperature with plants: urban parks, road trees, landscape within the vicinity of buildings and rooftop gardens. In addition, the surface temperatures could be reduced with rooftop gardens or vertical landscaping.

In high-density cities, land is scarce and there is little provision of space for the incorporation of urban greenery such as urban parks and landscaping. The integration of greenery in buildings also faces many constrains (Chen; Wong, 2010), in spite of some cases of success, like in Singapore, with the adoption of Green Plot Ratio by the local legislation (Ong, 2002).

Duo to the combined effect of shade and evapotranspiration, air temperature reductions from 1ºC to 3ºC can be achieved under the canopy in green areas, depending on the climate and soil conditions. According to Wong and Chen (2009), from the planning point of view, it can be found that smaller green areas strategically arranged or grouped around buildings should be largely promoted. This does not mean that large urban parks are not effective in terms of improving urban climate, but they are considered as a luxury to a heavily built-up environment, especially if rapid urbanization is experienced.

Within this context and assuming that the densification is inevitable and desirable from the point of view of urban sustainability, especially in megacities like Sao Paulo, the purpose of this research is to assess the cooling effects of vegetation in urban microclimate, especially during daytime, to counteract an increasing built density in a subtropical climate. The findings contribute to a land-based mitigation strategy, trying to answer partially what a changing climate will mean for cities and aiming for a more favourable energy balance in cities facing two climate-change mechanisms that can be superimposed: the global warming and the local daytime heat-island effect.

URBAN AND CLIMATIC CONTEXT OF SAO PAULO METROPOLITAN AREA

São Paulo is located at 23°32'S, 46°37'W, 60 Km far from the sea with altitudes varying from 720m to 850m. The city experiences hot, humid summers with air temperatures varying between 22ºC and 30ºC and mild winters between 10ºC and 22ºC. The metropolitan region, the 3rd biggest in the world, with more than 22 million inhabitants, had in 2014 the warmest January since 1943, when climatic data started to be regularly recorded in the city by the National Meteorological Institute (INMET) and the warmest February, with a maximum air temperature up to 36,4ºC. In other cities, like Porto Alegre, the Southern state capital, January 2014 was also the warmest in almost 100 years.

Accordind to PBMC (2013), in the future, besides mean temperature warming, an increase of extreme events is expected. January and February 2014 presented air temperatures above those observed ever and humidity values below those historically found. Whilst the historical climatological averages for these months are respectively 21,6ºC and 21,8ºC, the mean values recorded in 2014 were 24,2ºC and 24,3ºC and the highest measured air temperature since the meteorological station of the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of São Paulo (IAG-USP) recordings started were registered in both months: 31,6ºC. While both months are generally characterized by high rainfall amount and average relative humidity of 83%, the 2014 first two months had lower precipitation rates and recorded lower values of relative humidity (75% and 73% respectively). Thus, for this study, the incorporation of these months in the simulation is intended to be representative of an extreme event, characterized by higher temperatures and lower humidity rates.

Megacities like São Paulo are vulnerable to global warming and local warming effects, driven by urbanization. The PMBC is especially worried about the fast pace of vegetation suppression in Sao Paulo, both in the interspace of buildings as well as in the outskirts of the city.

Comparing the city of Sao Paulo´s population density with other cities in the world (Fig. 1), it is observed that even with an average density of 73.87 hab/ha (IBGE, 2011), similar to other cities, the density of Sao Paulo´s densest district is one of the lowest. As the availability of transport and infrastructure should be directly linked to urban density, it would be possible to think that there is an equitable distribution of these infrastructures throughout the city, which is definitely not true. São Paulo has some areas with reasonable availability of transport that does not necessarily have high values of population density and vice versa.

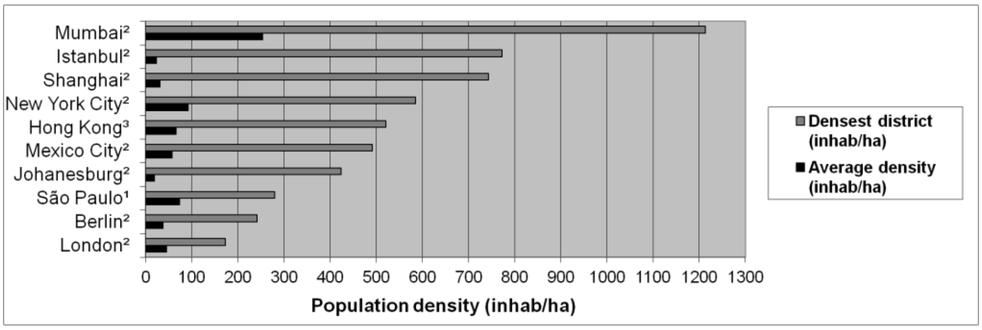


Figure 1: Big cities, their average density and densest districts.

Source: GUSSON, MADEIRA, DUARTE (2012) based on IBGE (2011), Burdett and Sudjic (2011) and Hong Kong Special Administrative Region (2012) data.

São Paulo is characterised by a heterogeneous urban structure, resulting from the rapid growth of the city during the 20th century. One of the effects of this growth is the social conflict of high-rise office towers and residential apartment buildings close to poor informal settlements (favelas). In addition, the distribution of vegetated areas is non-uniform in the city. While there are 35 parks, corresponding to 15 million m^2 (21% of the total area of Sao Paulo municipality), the downtown districts of Bras and Bela Vista are almost devoid of vegetation. Thus, few areas in the city are characterised by large amount of vegetation and street trees, usually in the wealthiest districts, mainly in the west zone of the city.

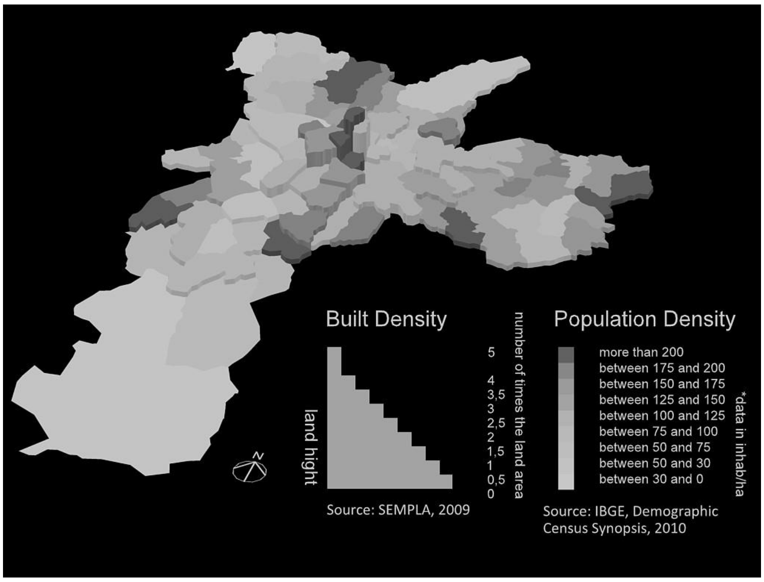


Figure 2: Built and population density in the city of São Paulo (by districts).

Source: GUSSON, MADEIRA, DUARTE (2012) based on IBGE (2010) and SEMPLA (2009) data.

The central area of São Paulo is formed by various districts, one of those is Bela Vista, chosen for this study due to its population density (the highest in the city) and for the built density (the 3rd higher), compared to a total of 97 districts in the municipality. Bela Vista shows the predominance of vertical residential buildings with heights varying between 10 and 20 floors. It also has one of the lowest green area per inhabitant, almost zero, according to Sao Paulo Environmental Agency.

FIELD MICROCLIMATE MEASUREMENTS

Microclimate monitoring was carried out from March 4th to April 29th of 2013 in the area of Bela Vista to register air temperature, relative humidity, solar radiation, surface temperature, wind direction and speed, aiming to previously calibrate the ENVI-met[1]4 *preview* for the parametric simulations. Figure 3 shows a nine-block area and in the middle of the central and densest block a Campbell Scientific meteorological station was set up in the ground floor of a residential building. In order to avoid obstructions for residents' circulation and for the equipment's protection, residents allowed the equipment installation in the building backyard, over grass and under a wooden pergola.

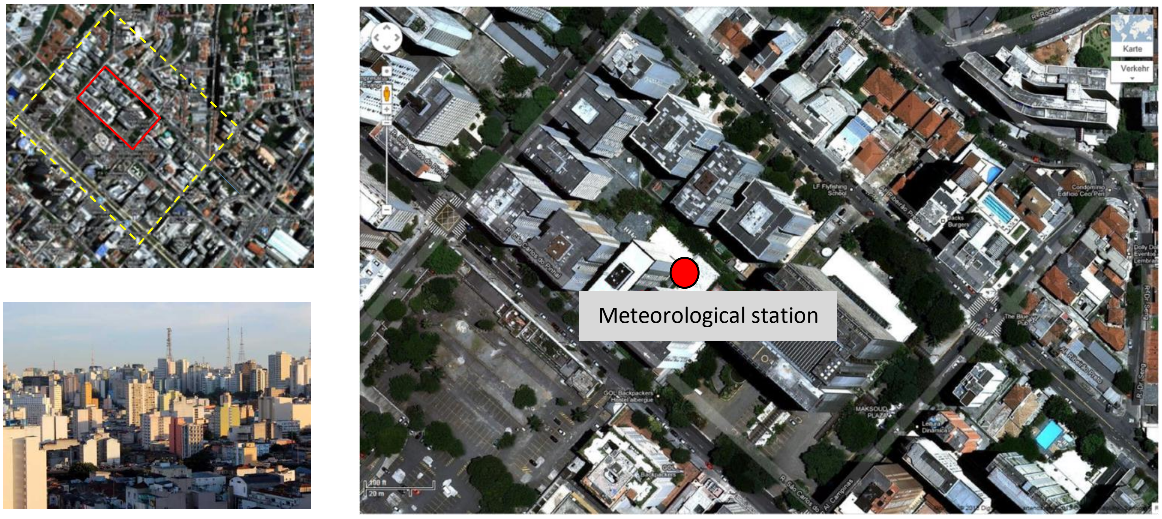


Figure 3: Location of the meteorological station in the middle of the densest block in Bela Vista.

Source: GUSSON, 2014.

CALIBRATION AND PARAMETRIC SIMULATIONS IN ENVI-MET MODEL

The ENVI-met three-dimensional microclimate model was chosen for this study due to its advanced approach on plant-atmosphere interactions in cities. ENVI-met is one of the few models that seeks to describe the major climate processes acting in the urban environment, including turbulence, the turbulent transport of sensible and latent heat, the radiation fluxes within the urban structures and the influence of vegetation. The model simulates aerodynamics, thermodynamics and the radiation balance in complex urban structures with resolutions between 0.5m and 10m according to the position of the sun, urban geometry, vegetation, soil and various construction materials by solving thermodynamic and plant physiological equations (Bruse; Fleer, 1998; Bruse, 2012; Huttner, 2012).

For ENVI-met 4.0 *preview*, the forcing feature was incorporated and it is now possible to define the diurnal variation of the atmospheric boundary conditions and the incoming radiation. It also allows developing much more detailed weather scenarios for testing purposes and producing results that are in good accordance with field measurements (Jansson, 2006). The input data are shown in Table 1. The solar radiation calculated as a function of the latitude was adjusted to measured radiation by applying 1,4 octas for low clouds cover and 0,4 octas for high clouds cover. The adjustment factor for solar radiation was 1 (100%), in accordance with the measured data. The only additional climate data (not derived from local measurements) was that for specific humidity at 2500m, obtained from the local airport Campo de Marte (ca. 3,3km north of the site).[2] The soil temperature for the upper layer was measured using Campbell 107 temperature probe and humidity was estimated with Simple Biosphere Model – SIB2.[3] The model showed close similarity between adjusted and measured data, providing reliable results for the parametric simulations.

[1] ENVI-met website: http://www.envi- met.com/
[2] Available at the University of Wyoming: http://weather.uwyo.edu/upperair/sounding.html
[3] Data provided by IAG Laboratory of Climate and Biosphere, University of Sao Paulo.

Table 1: Input configuration data applied in the ENVI-met 4 preview simulations

Start Simulation at day	26.04.2013
Wind Speed in 10m ab. Ground [m/s]	0.5
Wind Direction (0:N/ 90:E/ 180:S/ 270:W)	112.5
Initial Temperature Atmosphere [K]	300.44
Specific Humidity in 2500m [g Water/ kg air]	7
Relative Humidity in 2m [%]	50
Initial Temperature Upper Layer (0-20cm) [K]	291.76
Initial Humidity Upper Layer (0-20cm) [%]	50

For simulations, the starting day was defined based on pluviometric data collected from two fixed meteorological stations: one in the northern and other in the southern part of the city for the same period of Bela Vista measurements, which indicated the longest period with stable climatic conditions between April 26th-28th 2013, during autumn. Besides that, February 2014 was chosen to represent an extreme warm summer, characterized by higher temperatures and lower humidity rates registered in decades.

Initially a Base Case model was created and the input area domain was formed by 9 blocks of 100m x 100m (10.000m^2) each, which can be considered an average block size in Sao Paulo. In each block there are nine towers with 45m height (15 floors, average in Bela Vista), 20m x 20m each, representing a plot ratio of 5,4. The tower has a square shape plan that was planned to consider 4 housing units with 58m^2 each, per floor, and a population density of 3,5 people/apartment (total of 1764 inhab/ha).

Two other scenarios were created with different trees' distribution: a central park with trees covering an entire central block; and the same green area distributed in rows of street trees located in the perimeter of every block. In both cases, dense trees (LAI=4,6 m^2/m^2) and a soil type of sandy-clay-loam were chosen. Wind speed was kept constant in 0,5m/s in all scenarios, aiming to minimize convection effects and emphazise the effect of green and built density.

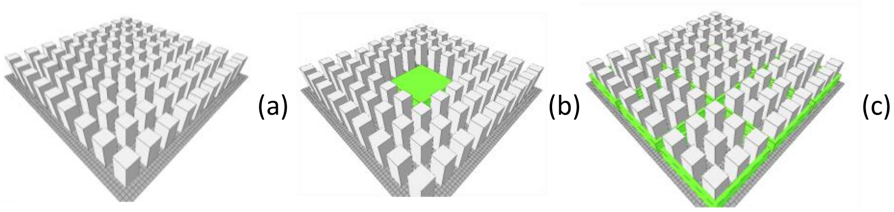


Figure 4: The three scenarios for ENVI-met model: (a) base case, only towers, (b) towers + central park, (c) towers + street trees

RESULTS AND DISCUSSION

All results are shown for 15h LST, coinciding with the maximum air temperature in all cases (Figure 5). As expected, in autumn, April 2013, with a mild climate in Sao Paulo, air temperature differences are minor, up to 0,5ºC, comparing the scenarios a and b, in and around the park, and about 0,3ºC comparing a and c. Concerning the distribution, the oasis effect is more pronouced in scenario b than c. In February 2014, the extreme warm summer this year, air temperature differences become more significant and the effect of vegetation is slightly more pronounced showing air temperature differences up to 0,6ºC comparing scenarios a and b and about 0,2ºC comparing b and c. On the other hand, the effects of the mutual shading of buildings and the vegetation contrasts with the warmer surfaces of the streets and the unshaded spaces between buildings, showing mean radiant temperature differences up to 13ºC in and around the park comparing the scenarios a and b, even during the mild April 2013. In scenario c, mean radiant temperature is lower along the shaded streets, although inside the blocks, scenario b performs better, configuring an oasis effect. Going to the extreme summer, February 2014, the picture is about the same, but with higher temperatures in the three scenarios, being mean radiant temperature in the scenario b about 10ºC lower than the scenario a. In scenario c the benefits of tree shading are evident on the mean radiant temperature along the streets, under the canopies, but the effect is local, and do not spread over the blocks (Table 2).

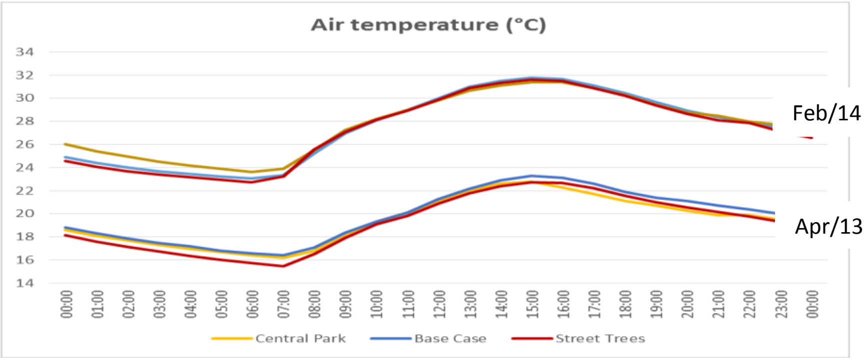
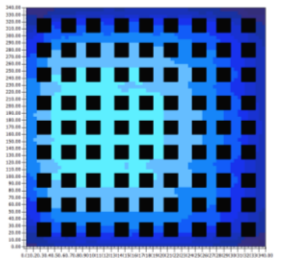
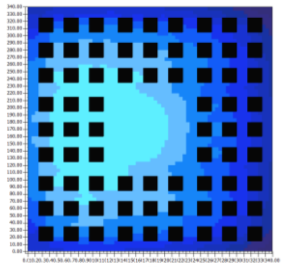
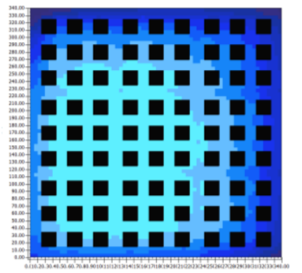
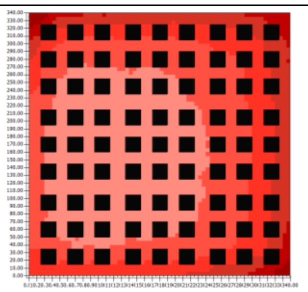
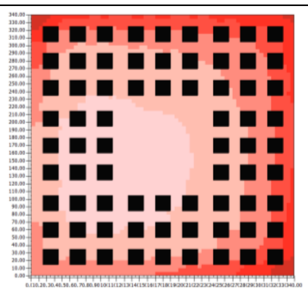
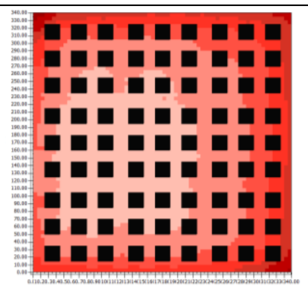
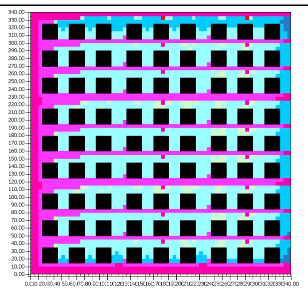
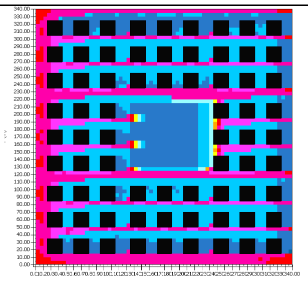
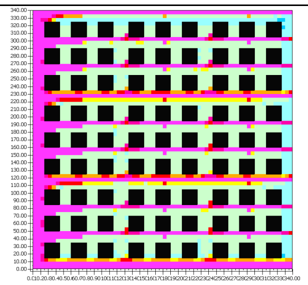
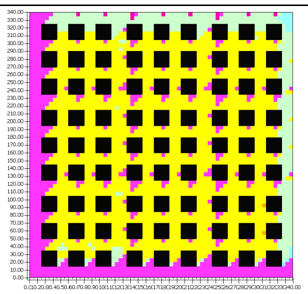
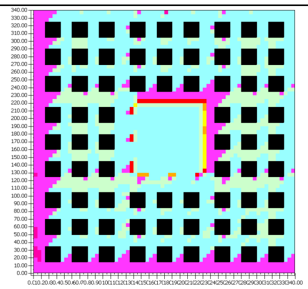
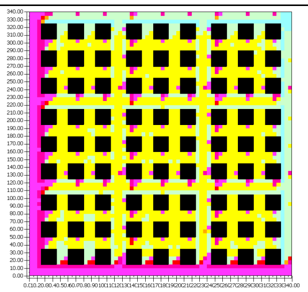


Figure 5: Air temperature results in both seasons, showing the highest air temperature at 15h LST.

Table 2: Simulation Results for 15h LST

	Base Case – only towers (a)	**Central Park Scenario (b)**	**Street Trees Scenario (c)**	**°C**
Air temperature – Apr/13				< 22,8° 22,9°C 23,0°C 23,1°C 23,2°C 23,3°C 23,4°C 23,5°C 23,6°C > 23,6°
Air temperature – Feb/14				< 31,4°C 31,6°C 31,8°C 32,0°C 32,2°C 32,4°C 32,6°C 32,8°C 33,0°C > 33,0 °C
Mean radiant temp – Apr/13				< 31°C 36°C 41°C 46°C 51°C 56°C 61°C 66°C 71°C > 71°C
Mean radiant temp – Feb/14				< 31°C 36°C 41°C 46°C 51°C 56°C 61°C 66°C 71°C > 71°C

Based on simulation results, an empirical adaptive thermal comfort index developed for local conditions was applied. The Temperature of Equivalent Perception - TEP (Monteiro; Alucci, 2011) was calculated based on the mean values for the central block in the three scenarios for the two periods, at 15h LST. Wind speed was 0,5 m/s, the same adopted for the simulation input.

Table 3 – Results for TEP = -3,777 + 0,4828 . Ta + 0,5172 .Tmrt + 0,0802 . Rh – 2,322va (oC)

	April 2013					February 2014				
Scenario	Ta (ºC)	Tmrt (ºC)	Rh (%)	v (m/s)	TEP	Ta (ºC)	Tmrt (ºC)	Rh (%)	v (m/s)	TEP
only towers	23,3	43,7	45,8	0,5	**32,6**	31,9	52,3	34,9	0,5	**40,3**
towers+ central park	22,8	33,2	48,1	0,5	**27,1**	31,3	43	36,4	0,5	**35,3**
towers + street trees	23	42,2	47,3	0,5	**31,8**	31,5	50	36,2	0,5	**39,0**

CONCLUSIONS

In both seasons, air temperature differences are small among the three scenarios, around 0,5ºC. In spite of that, the lower mean radiant temperature in the central park (scenario b) provoke an increase in comfort levels according to TEP, around 5ºC, characterizing what Erell *et al*. (2011) called park cool island, an oasis effect even in-between towers in a high-density context. On the scenario c, the effect is noticeable when compared to the base case (scenario a), but localized under the trees' canopies and the oasis effect do not spread over the blocks. None of these scenarios will reverse long-term warming trends but combinations of these strategies can moderate the extreme of climate events in cities.

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The Life and Death of the Minnesota Experimental City: An Experiment in Utopian City Planning

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ABSTRACT

Sustainability at the macro scale of settlement has been an aspect of the design of cities since our earliest history as urban dwellers (e.g. human settlements in ancient China, Egypt, Greece, India, Asia Minor, the Mediterranean world and South and Central America). The Minnesota Experimental City (referred to by its planners) was imagined initially by a university professor and a newspaper publisher, and was planned by working groups – meeting at the University of Minnesota - which included designers, planners, business people, government leaders, sociologists, educators, theologians, scientists, and economists, and ultimately supported in its early phases by both the federal government and the State of Minnesota. The goal was to plan, develop, and build – through a public/private partnership - a healthy environment for a new city of 250,000 people for northern Minnesota and to be constructed from the early 1970's to the mid-1980's. It would incorporate such technological innovations as car-free zones with people-movers, waterless toilets, a power-generating system fueled by both the burning of garbage in pollution-free furnaces and the use of windmills, and partially domed, climate-controlled, city centers. The goals of the city included life-long learning; social integration among and between religious, racial, age-specific and ethnic sub-groups; and values which looked not just forward but back to a feeling of community which emphasized "good food, good friends, and a good relationship to the earth." In essence, the Minnesota Experimental City embodied the principles of social, economic and environmental sustainability. This paper discusses the salient features of the Minnesota Experimental City and its relevance in the present context.

INTRODUCTION

As urban planners around the world confront the critical issues of the twenty-first century—expanding population, rapid urbanization, limited global resources, increased demand for food production, and protection of a fragile environment - this paper narrates the story of the Minnesota Experimental City (called MXC) – a livable sustainable new city of 250,000 people, planned for northern Minnesota in the central United States, intended to be constructed from the early 1970's to the mid-80's.

It's often the case that great big ideas like the MXC have larger-than-life characters behind them, and the MXC is no different. The story of the birth of the MXC idea is the story of Athelstan Spilhaus and Otto Silha – two men who met at the right time – (1965) - and in the right city and state – (Minneapolis, Minnesota – known at the time for its progressive politics) - each with a history of thinking creatively as they operated in their very different spheres – (Spilhaus, the world of science and education in his position of the Dean of the Institute of Technology at the University of Minnesota; Silha, the worlds of newspaper publishing and civic philanthropy). The MXC was planned by working groups which included designers, planners, business people, government leaders, sociologists, theologians, scientists, and economists. Their goal was – through a public/private partnership - to plan, develop, and build a healthy, sustainable environment for the city's inhabitants, which would incorporate such technological innovations as car-free zones with people-movers, waterless toilets, a power-generating system fueled by both the burning of garbage in pollution-free furnaces and the use of windmills, and a domed, climate-controlled downtown area.This paper will examine these forward-thinking technological innovations, but also the human-centered goals of the planners (among them futurist Buckminster Fuller, urbanologist Harvey Perloff, theologian Martin Marty, and economist Walter Heller) which included life-long learning; social integration among and between religious, racial, age-specific and ethnic sub-groups; and values which looked not just forward but back to a feeling of community which emphasized "good food, good friends, and a good relationship to the earth" (TIME, 1973).

It is helpful to understand the planning context in which these initial conversations between Spilhaus and Silha took place. The Housing Act of 1949 had launched the "Urban Renewal" movement in American cities. Neighborhoods considered "blighted" in dozens of cities across the country were cleared at federal and local expense, and land given to developers for redevelopment. The Housing Act of 1954 had made this redevelopment even more attractive to developers by providing FHA-backed loans to build housing. In 1956, the Federal-Aid Highways Act encouraged city and federal planners to construct new highways to provide easy access into central cities, often destroying healthy existing inner-city neighborhoods in the process. These actions, on top of the housing acts of the 30's and 40's which served to increase segregation and the growth of government-funded slum housing, along with the growth of suburban areas as city residents fled increasingly more troubled city centers, resulted in the sense that the American urban experience had failed. In 1961, Jane Jacobs in *The Life and Death of Great American Cities* began to raise strong questions about what had gone wrong at the hands of planners and government officials. There was a deep-felt concern that society was headed in the wrong direction in its ability to address the social issues of the day, e.g. segregation (of age groups as well as races), the environment, and education, but that all the tools were at hand to move in another direction.

By the mid-1960's, cities and their citizens were in turmoil. Polluted rivers were catching fire, spurring the birth of the environmental movement in the United States. This and the race riots that began in 1965 and continued through the remainder of the decade resulted in the sort of thoughtful – and urgent – discussions that Spilhaus, Silha, and leaders in business and industry in Minneapolis were engaged in, concerning the future of cities.

Add to this milieu the sense – based on evidence such as the successes of the Apollo moon shot program – that technological advances could solve our problems and move us forward. There was the sense also – a sort of World's Fair type of thinking – that the inventiveness and marketing know-how of the American people had not been applied to the problems of cities and housing (Spilhaus had directed the U.S. exhibit at the Seattle's World's Fair, and MXC planners were inspired by Moshe Safdie's Habitat housing complex built for Expo 67 in Montreal).

The Minnesota Experimental City was never built. The paper will look to answer the question, "why not?" and seek, also, to describe aspects of the city's design, features, and goals which might find new life in planning the healthy communities and sustainable habitats of today and tomorrow.

NEW TOWNS TO SUSTAINABLE TOWNS

The idea that we could re-imagine or re-invent cities to make them more "uplifting" places of habitation was, of course, not a new idea. Hippodamus (c. 498- c. 408 BC), a native of Miletus, Greece invented the art of planning cities and designed port towns of Piraeus and orthogonally planned towns such as Olynthus, Priene and Miletus. Conscious planning of cities reemerged in Europe during the Renaissance with prime objective to glorify a ruler or a state and partly aimed at improving circulation and providing military defense. From the 16th century to the end of the 18th, many cities were laid out and built with monumental splendor rather than health and comfort provisions for citizens.

The modern origins of urban planning lie in a social movement for urban reform that arose in the latter part of the 19th century as a reaction against the disorder of the industrial city. Many visionaries of the period sought an ideal city, yet practical considerations of adequate sanitation, movement of goods and people, and provision of amenities also drove the desire for planning.

New town developments have served many needs throughout history, including the following, according to William Alonso (1973): a) the acculturation and absorption of migrants, as in Israel and Australia; b) the development of frontier regions, ranging from tiny ones (Holland, Israel) to vast ones (the nineteenth-century American West, Siberia, and the center of South America); c) the exploration of concentrated resources (Ciudad Guayana, Venezuela and Kitimat, BC) and of extensive ones (central place systems such as the nineteenth-century American Midwest); and d) symbolism and politics (Washington, Brasilia).

In the United States, the Cities Beautiful movement, which architect Daniel Burnham was credited with founding, and which the Chicago Exposition of 1893 was credited with starting, influenced civic-minded citizens and planners in large cities and small towns across the nation. While the City Beautiful movement was based on the principles of Beaux Arts design, it really wasn't about beauty for its own sake, but for creating social order by instilling civic and moral virtue among the population. In 1906, Burnham and his assistant Edward Bennett designed a plan for the Chicago, which was the first comprehensive plan for the controlled growth of an American city. Happening at roughly the same time, and meshing with the same kind of intentions that the Cities Beautiful movement had was Ebenezer Howard's Garden City movement in England, founded in 1898, which was a reaction to the dirty, unhealthy conditions of cities caused by the Industrial Revolution. In the United States, bedroom suburbs such as Radburn, NJ, designed by Clarence Stein and the "greenbelt" towns continued the European Garden City tradition during pre-World War II years. In 1962, the modern new town community of Reston, VA, (Columbia, MD, came later) provided social and economic components of community as well as the simple physical aspects of the earlier new towns.

Table 1: Sustainable Urban Form Matrix

Design Concepts	Neo-traditional Development	Compact City	Urban Containment	Eco-city	MXC
Density	Moderate - 2	High – 3	Moderate – 2	Moderate – 2	Moderate - 2
Diversity	High – 3	High – 3	Moderate – 2	Moderate – 2	High – 3
Mixed land use	High – 3	High – 3	Moderate – 2	Moderate – 2	High – 3
Compactness	Moderate – 2	High – 3	Moderate – 2	Low – 1	Low – 1
Sustainable transportation	Moderate – 2	High – 3	Moderate – 2	High – 3	High – 3
Passive solar energy	Low – 1	Low – 1	Low – 1	High – 3	High – 3
Greening – ecological design	Moderate – 2	Low – 1	Low – 1	High – 3	High – 3
Total Score	15 points	17 points	12 points	16 points	18 points

In the late 20th century the term sustainable development came to represent an ideal outcome in the sum of all planning goals. As advocated by the United Nations-sponsored World Commission on Environment and Development in Our Common Future (1987), sustainability refers to "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The latter point has been labelled as 'inter-generational equity'. More recently, sustainable development is defined as " a dynamic process which enables all people to realize their potential and to improve their quality of life in ways which simultaneously protect and enhance the earth's life support systems," (Forum for the Future). While there is widespread consensus on this general goal, most major planning decisions involve trade-offs between subsidiary objectives and thus frequently involve conflict. Jabareen (2006) delineates seven design principles for attaining the goals of sustainable urban development and identifies four urban forms that contribute to the overall sustainability of cities. Neo-traditional Development, Urban Containment, Compact City and Eco-City are the four identified sustainable urban forms comprised of combination of seven design principles or concepts viz a)

Compactness b) Sustainable Transport c) Density d) Mixed Land Uses e) Diversity f) Passive Solar Design g) Greening. The MXC epitomizes the design principles of sustainable urban development and is a forerunner to the present day eco-cities, as can be seen in how the MXC scores using Jabareen's (2006) Sustainable Urban Form Matrix, measuring the seven principles above, and comparing the MXC to the four sustainable urban forms listed, shown in **Table 1**.

OVERLEAP

By 1967, multi-disciplinary studies for planning the MXC were initiated at the University of Minnesota, under the direction of Walter Vivrett, professor of architecture and planning. Otto Silha was by now the chair of a Steering Committee of 23 well-known individuals from a broad variety of disciplines from around the nation. The word "overleap" was used to describe what the MXC hoped to achieve: "at once an advance into future possibilities and a break with past constraints" (Vivrett, 1972). It was determined that the best avenue for arriving at a concept for the MXC would be to initiate "workshops" which would focus on specific areas:

- Education - Health, medical and environmental health
- City-building technology
- Communications
- Waste management and pollution control
- Transportation (people, goods, and mail)
- Energy and energy transmission

The workshop participants, numbering almost 200 people, met for roughly three days each from late 1967 through early 1968. They were asked to identify, in their areas, what was "state of the art, and then identify major gaps and issues and areas for potential innovation – critical for a city that was truly "experimental."

One might discount all of this as the efforts of a few scholars and interested business people. By February of 1967, however, grants from three government agencies (Housing and Urban Development, Health Education and Welfare, and Commerce) and 10 corporations – totaling around $300,000, or more than $2 million in today's dollars – were in place to fund the planning stage of the project. Vice-president Hubert Humphrey had signed on as a supporter, as had the Minnesota State Legislature.

WHY A NEW CITY?

The concepts of dispersal and building-from-scratch were critical for the success of a new experimental city. Attempts to repair the existing fabric would present problems having to do with "local traditions, outmoded building codes, restrictive legislation, and the consequences of unplanned, unhealthy growth" (Spilhaus, 1968) in addition to the vested interests of local business and industry. A "dispersed" city, located no less than 100 miles from an existing urban city, would be able to offer the advantages of an existing city but – with a defined perimeter and surrounding reserved land – it could not suffer from unplanned growth. The "built-from-scratch" aspect would allow new innovations in services, waste-management, pollution control, and communication to be fully implemented from the start, and serve as a test environment for other new cities.

A third aspect of the initial concept was that of "urgent need" – the urgent need to build and populate an "instant" city fully and quickly so that it might soon function as the kind of sociological and technological laboratory – the core of the "experimental city" concept - that might lead the way for other new cities and the repair of the environment into the 21st century. It was estimated that the MXC would cost about $4 billion to build ($26 billion in today's dollars).

While it is interesting to focus on the technological and planning aspects of MXC, it is important to state that from an early point in the conceptual phase it was the community and human values that were stated as the main goals of the project – the phrase "people-oriented, technologically advanced" was often used as a descriptor. Spilhaus said, "We must not force people into what is technologically easy, but find a technological solution which is practical and closely meets their desires" (Spilhaus, 1968).

The overarching goals were these (Vivrett, 1972): “a. man can creatively mold his environment; b. he can, in a positive and constructive manner, unite the resources of private technology with public authority; and c. he can re-orient social, economic, and physical forces to serve people.” The futurist Buckminster Fuller, a member of the Steering Committee, discussed the role of a city of the future as being “metaphysical,” offering a forum for the exchange of ideas, learning and culture, and not just goods.

MXC PLANNING PRINCIPLES

It’s important to make clear that site selection was an important aspect of the planning process. A number of sites around the state of Minnesota were considered, with two sites selected as finalists, both of them about two hours north of Minneapolis-St. Paul in rural areas, and both of them in areas of the state that were struggling economically.The basic planning principle that the MXC was based upon was Walter Christaller’s “Central Place Theory” which was developed during the 1930’s in Germany. The theory consisted of two basic concepts – that of “threshold,” which is the minimum population that is required to bring about the provision of certain good or services, and that of “range,” which is the average maximum distance people will travel to purchase goods and services.

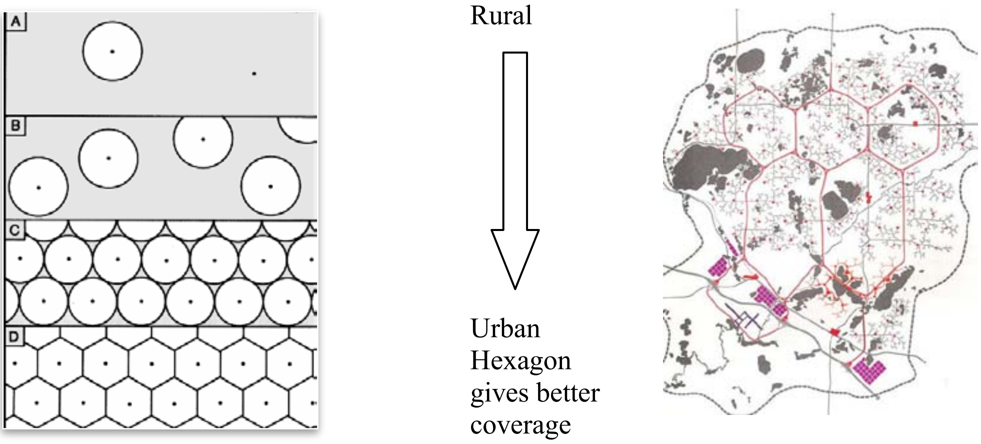

Figure 1 MXC development plan, combining hierarchical systems of centers with existing development patterns (Minnesota Experimental City Authority – Preliminary Report on Urban Design, 1973).

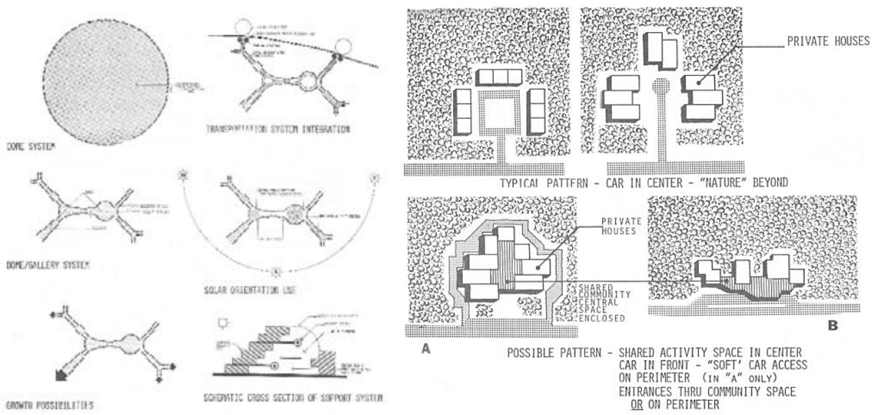

Figure 2 MXC development plans, combining hierarchical systems of centers with existing development patterns (Minnesota Experimental City Authority – Preliminary Report on Urban Design, 1973).

If you begin to “densify” areas of range you get a hierarchical system of centers, with the hexagonal shape ultimately giving better coverage than a circle. This system of hexagonal transportation networks was then laid out over existing potential communities in the initial master planning, as shown in **Figure 1.**

At the level of the community and neighborhood, as in **Figure 2,** built forms and development were laid out to maximize solar gain (images to the left), and to accommodate shared community space and close connections to nature (images to the right).

INFRASTRUCTURE AND SUPERSTRUCTURE

Technologically, the most important component of the MXC was its coordinated infrastructure and superstructure – its tunnel system, as in **Figure 3**. All transportation of goods and services, waste and utilities, and construction materials (small-sized components which could be assembled and disassembled for different configurations) would be handled through the tunnel system. Part of the tunnel system would be a network of environmentally-friendly features – solid waste would all be handled through an underground system that would allow for recycling of materials, the air would be scrubbed of pollutants, waste water would be reused for cooling and then recreation, and the infrastructure would do double-duty as superstructure.

People would arrive by vehicle at the edge of the city and would then be transported through a “pod” system of people movers, with semi-private “cabs” and the ability to select one’s own destination in a way that was more flexible than bus transportation. These cabs would provide door-to-door transportation to both low-density and high-density living and community structures, as in **Figure 4.**

It was very important to the planners that the communication network for the MXC also be part of the tunnel system. The substructure would be wired with coaxial cable to reach anywhere a telephone might conventionally be located. A wiring system to service radio frequency transmission would also be included. It was anticipated that the communication system would be used for high-speed connections to computers and video monitors which would be used for – among many anticipated uses - shopping, banking, crime prevention and the de-centralizing of learning and health care. It was planned that medical care would be made available through a series of care centers which would provide appropriate care at various levels, with computer connections back to central medical facilities for advice from specialists. Health care would be delivered as a “utility,” with easy access for all.

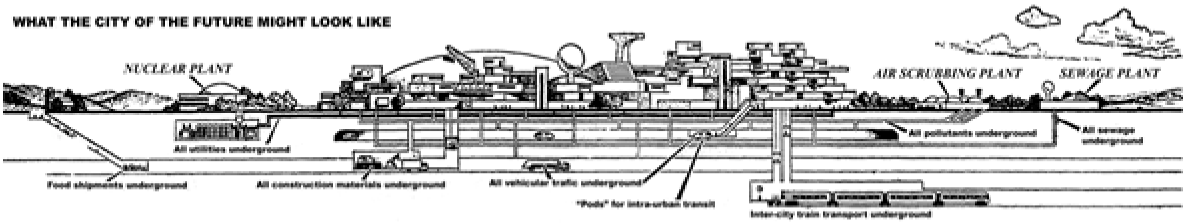

Figure 3 Cross-section of the MXC superstructure and tunnel system (New York Times, 1967).

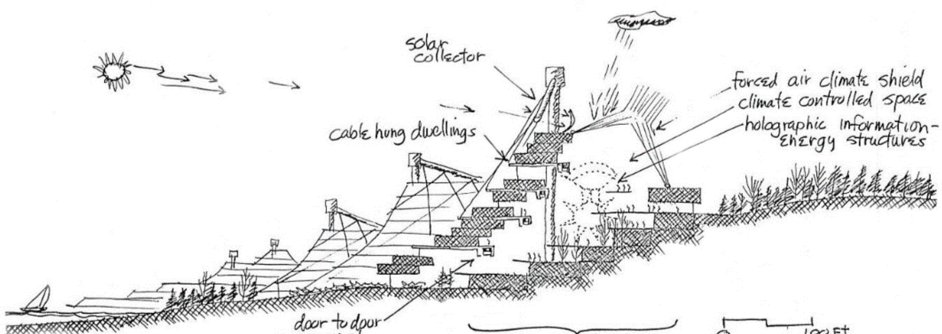

Figure 4 High-density community form, with maximized solar access and climate-controlled public space (Minnesota State Historical Society – MXC Authority Collection).

LIFE-LONG LEARNING

Perhaps one of the most interesting innovations in the MXC plan was in the area of education. The city would be constructed with no schools, but would instead serve as a life-long learning laboratory. Everyone would be a learner and everyone would be a teacher. Learning would occur everywhere within the city. There would be no schools, but instead learning centers located throughout the city in homes, businesses, and public spaces. These would include Beginning Life Centers for very young children, Stimulus Centers for films, tapes, sounds and spells, Gaming Centers for the study of complex realities in a simple fashion, Project Centers where people could work on experimental outcomes, Learner Banks where tools, equipment, print and non-print materials could be checked out, and Family Life Centers where families could learn together (Minnesota Experimental City Authority – Education, 1973).

FINANCING AND MANAGEMENT

With a price tag of over $4 billion, who was to pay for and manage the MXC? The planners of the project suggested several options for management. One would be to have a quasi-public, quasi-private corporation run the city as a public utility (similar to the model that was ultimately used at the London Docklands); another would be to view the city as similar to a large Disney-style hotel complex with lodging, shops, restaurants, and transportation systems, with public services possibly contracted out to private entities. In terms of who would pay the initial price tag for infrastructure, it was hoped that business and industry – recognizing the opportunity that the city would provide as a laboratory for new technologies of pollution control, transportation, communication, and construction - would be willing to invest in the up-front construction costs. Additional costs could be financed through bundled FHA mortgages.

FATE OF THE MXC

The initial project reports were completed in 1969, and the workshops continued their studies. The project lost a strong supporter at a high level when Hubert Humphrey lost his bid for the U.S. presidency in 1968, and MXC gradually lost local support as the state legislature tipped from more liberal to more conservative from 1968-1972. The University of Minnesota at the time was also substantially funded by the legislature, and as the legislative makeup changed, state government was less supportive of the University's MXC efforts. By late 1972, the final site had been chosen for the project. In January 1973, the final planning reports were issued. But by February of that year it was also the case that local politics had begun to signal the end of the project.

Locally, the MXC project - grounded in environmental innovation - became a victim of the concerns of those who treasured the local environment of Aitkin County, MN, the wooded, rural county which was ultimately selected as the site for the MXC. While many residents of the county welcomed the opportunities which the project would bring, many feared the loss of property and peacefulness. In 1973, TIME Magazine published an article called "The Newest New Town" which spoke positively about the prospects for the MXC. It was the last hoorah, followed by these grim headlines in the Minneapolis Star Tribune from February through May of 1973:

2/8 "MXC Prospects Not Bright in Legislature"
2/14 "Opponents Term MXC a Trojan Horse"
2/16 "MXC Threatens Good Hunting Area"
2/20 "Petitions Opposing MXC Presented to Governor"
3/13 "PCA Recommends Dropping MXC Plan"
3/28 "Senate Sub-Committee Votes to Cut Off MXC"
4/4 "House Sub-Committee Votes Against MXC"
4/5 "MXC Bill Dead"
5/24 "MXC May Be Moved to VA, FL, or OH"

Things were also happening in the larger arena that helped to seal the fate of the MXC. The country was involved in an unpopular war which escalated after the election of Richard Nixon in 1968 and didn’t end until 1975. From 1973 through 1975 the country experienced what some considered the most severe recession since WWII, with oil shortages, rising interest rates, and the reduction of real income and consumer spending. The notion that we could tackle any challenge if the ideas and the effort were there seemed like an idea whose time had passed. Locally, the MXC project - grounded in environmental innovation, with a tightly interwoven connection between human development and the landscape - became a victim of the concerns of those who treasured the local environment of Aitkin County, MN, the wooded, rural county which was ultimately selected as the site for the MXC. While many residents of the county welcomed the opportunities which the project would bring, many feared the loss of property and peacefulness.

CONCLUSION

Those who contributed to the imagineering of the MXC should recognize aspects of the design in today’s world. Forty years later, we live in a world where the environmental issues of air quality, resource management, and land use are more important than they have been at any time since the 70’s. On-line learning and high-speed internet communication were just speculation in the 60’s – now they’re part of how we learn and communicate. The type of large scale building and planning of “instant” cities that characterized the MXC is now happening in the construction of new cities in India and China. The “cradle to cradle” use of resources we saw proposed for the MXC is now an aim for consumers, industries and nations.

Criticism has sometimes been leveled at the MXC for its top-down planning approach, conceived by an “elite” group of academics and businessmen. Its approaches, however, to sustainable land use, net-zero energy use and waste management, communication, education and health delivery systems still constitute the “overleap” of innovation that was the MXC’s goal. Forty years later, perhaps, the open-source, bottom-up nature of current innovation might take some inspiration, especially in developing societies, from the ideas of an experimental city that was many years ahead of its time. While the “compact city” model is viewed by many as the best answer to a more sustainable urban future, perhaps the idea of smaller - yet dense – communities which are closely tied to nature is more compatible with the patterns that have satisfied our needs for communal habitation throughout history.

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Towards the Improvement of Cooling Energy and seismic performance in Timber buildings using GIS and interactive Database

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ABSTRACT

By increasing the thermal mass of building components, in order to improve its thermal inertia, the whole structure mass rises and therefore reduces structural performance of timber buildings in seismic areas. Italian codes establish restrictive limits for the design of building, particularly in southern regions because of a high seismic activity. In order to answer the question »How can the summer behaviour of timber buildings be improved without worsening their seismic performance?«, Fraunhofer Italia, Free University of Bozen-Bolzano and Trees and Timber Institute CNR – IVALSA developed the research project TIMBEEST, which combines quantities belonging to different engineering branches (energy and seismic) towards their best compromise.

Within this research project, Fraunhofer Italia developed an interactive tool composed of database and Geographical Information System (GIS). This tool stores and analyses data, as well as it allows researchers and professionals to manage and evaluate the interaction of energy and structural characteristics of timber building components during the design phase across the Italian territory.

Starting from energy and structural indicators (the Cooling Degrees Days for the Typical Reference Year and the Seismic Response Spectra, respectively) by a spatial discretization based on Italian Provinces, maps with a classification of the Italian territory were created. Such classification combines energy and seismic indicators to evaluate their impact on buildings.

In order to improve the passive cooling performance of timber buildings on the basis of the classification of environmental and structural indicators, enhanced building components has been developed and presented by the interactive tool.

INTRODUCTION

Italy is a country characterized by an intense and widely spread seismic activity (Civil Protection Department) and high temperature during summer (Pinna, 1978), especially in southern areas. For this reason the TIMBEEST research project studies strategies to improve of the summer behaviour of timber buildings across the Italian territory by using thermal mass without worsening their seismic performance.

Since 1970s, researchers have studied the effect of thermal mass on energy demand and cooling/heating peak loads (Robertson (1986), Brown (1990)). Furthermore, the improvement of thermal

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building performance through the optimization of thermal mass layer distribution and its effective thickness has been investigated (Baverstock (1986), Shaviv (1988), Kosny and Kossecka (1998), Al-Sanea and Zedan (2001), Paradisi et al. (2012)).

Timber technology presents an excellent structural performance in seismic areas, but its low thermal inertia (compared to clay block or concrete buildings) reduces the energy performance in cooling period. Because of the timber technology is rare or even absent in Central and Southern Italy, it is an opportunity to investigate the technological feasibility and effectiveness of timber buildings, considering both thermal performance and structural implications. Beside its specific goals, TIMBEEST research requires a huge effort in data management because of data intersection and influences from energy and structural branches. This project requires to be managed in flexible way considering continuous alignments and integrations and even changes. In order to satisfy those requirements, an interactive tool based on databases seems to be the best solution.

TOOL STRUCTURE

At building and city level many studies discuss methodologies to store, manage data and catalogue solution in order to create cognitive tools, which enables professionals to visualize data, provide a global interpretation of information and support the decision-making process. Within the available methodologies, the Geographic Information System (GIS), based on the geo-referencing process, and database can be used as a digital tool to provide a support for analysing and managing large sets of data.

The collection and spatial data analysis provided by GIS is necessary for advanced urban planning which focuses on specific topics, i.e. energy management (Fistola, 2010). Coors and Xu (2012) proposed an integrated approach for sustainable assessments of urban area in Stuttgart through GIS cartographies. Fabbri et al. (2012) used GIS tool to collect data regarding energy class of existing buildings in order to suggest a zone energy indicator for evaluating the city. Ascione et al. (2013) developed an analytical methodology combined with GIS, which aims at characterizing energy performances of new and existing buildings in order to allow sustainable planning for energy-oriented cities. The application of database in research projects has been used by Thomson and Hardin (2000), who showed that the efficiently handled data can substantially improve the quality of planning and decision-making process. Sala, Romano and Boganini (2011) developed an interactive database collecting different technologies and construction systems of Mediterranean areas in order to support professionals in the development of a complete project analysis in several specific areas. Moreover, Attia and Wanas (2012) created for the city of Cairo an online source database of building materials, building envelopes and their characteristics, which influence energy consumption in order to support professionals during the design phase. All these researches list up specific characteristics which belong to different branches avoiding their correlations and do not focus on timber buildings.

Based on previous experience of the interactive tool “Timber Construction” (iPad application, Benedetti, 2010), and considering the complex structure of TIMBEEST research project, interactive tools are identified as the best solution for dissemination purposes. Considering the potential of interactive databases and GIS to intersect data at different levels and manage information effectively, the TIMBEEST interactive tool has been developed in order to manage contents throughout all research phases. It is composed of the following parts: a) databases created by FileMaker Pro 11 software, which are structured in three main databases and several sub-databases linked together; b) external GIS database made using Quantum GIS software, which correlates analysed data to Italian territory in order to support databases in point a). A common User Interface (UI) provides a rapid access to the content of three research phases of TIMBEEST project and allows navigating through them easily. These research phases are: 1) state of the art (geographical context, environmental restraints and analysis of standard building components); 2) analysis and simulation of improved building components; 3) results and comparison of previous phases. Each of these phases is structured by the three sections throughout they are developed, which are: a) definition of the specific objectives; b) methodology; and c) collection and comments of the results (**Figure 1 a)**. The UI switches between research contents and sets of documents by navigational tabs, as shown in **Figure 1 b**.

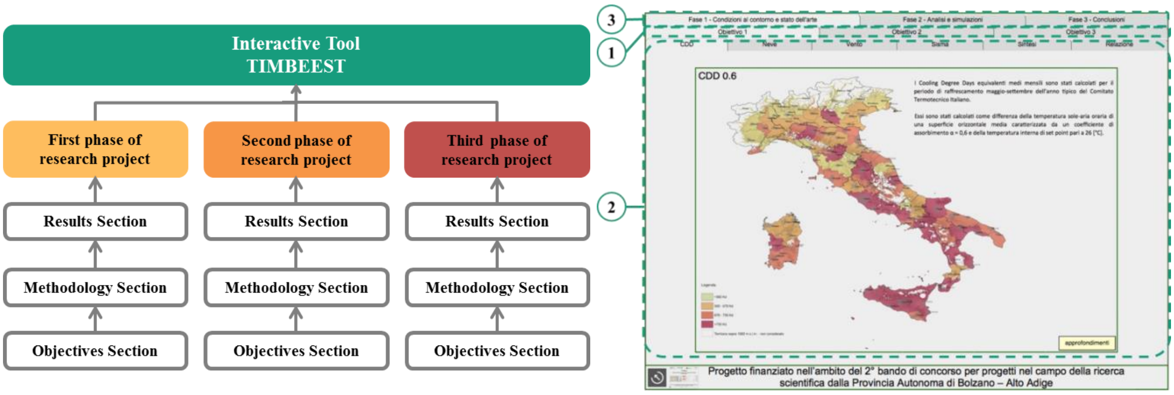

Figure 1 (a) Scheme of TIMBEEST interactive tool; (b) User interface for each phase of research project: 1) objectives; 2) methodology; 3) results.

OBJECTIVE AND METHODOLOGY SECTIONS

Objective section

The first phase of research project is focused on geographical context and environmental restraints, which affect thermal and seismic performance of buildings. Furthermore, the standard building components are identified and analysed. The objectives of the first phase are: a) to manage GIS data of physical features regarding environmental restraints such as equivalent Cooling Degree Days (CDD), horizontal elastic response spectrum (S_e), snow load (q_{sk}), wind load (p) and of a synthetic indicator, by mapping Italian territory at Province level; b) to manage energy and structural data of standard building components by the design of a database considering the most common timber technologies – Platform Frame (PF) and Cross-Laminated-Timber Panels (CLT) (Benedetti et al., 2010).

The second phase of research project develops and analyses improved building components by thermal mass in order to find the best compromise between summer thermal performance and seismic performance. Its objectives are: a) to outline suitable solutions for lightweights building components throughout a literature review regarding summer building performance and possible improvements in cooling period; b) to manage throughout a database energy and structural data of improved building components (with additional thermal mass); c) to summarize 256 dynamic simulations made by TRNSYS software for 110 capital cities of the Italian Provinces referred to standard and improved building components, respectively; d) to collect and visualize data of monitoring campaign of two Test Cells in order to validate thermal simulations; e) to manage 60 modal dynamic linear analysis of improved building components in order to evaluate the limit of thermal mass application in timber structures, which accomplish summer thermal improvement without worsening seismic performance of structure. The objectives c), d) and e) are going to be developed during the next months. Thence, the available results are not validated yet.

Furthermore, the third phase of research project will start at the end of year 2014 and it will include results of energy and seismic simulation and comparison of standard and improved building components in order to provide a quick overview of adopted solution.

Methodology section

The methodology section explains the procedures used to develop the scientific contents. This section corresponds to each objectives and it is integrated into the UI tabs (**Figure 1b, point 2**). Since the specific procedures exceed the goal of this paper, their details are not presented. It is possible to find such information in the research paper of Ratajczak et al. (2014). submitted to 30th International PLEA Conference 2014 and under the acceptance procedure.

RESULT SECTION

The result section visualizes specific phase outcomes in order to facilitate data analysis, to provide inputs for further steps of the TIMBEEST and to enhance the future implementation of the tool. These outcomes are gathered in result databases, and are correlated to different sub-databases and GIS database, as illustrated in the flow chart (**Figure 2**).

In detail each phase of TIMBEEST is made of different result databases, as many as the specific objectives. The following result databases are developed or will be implemented:

1. Result database of the first phase:
   a) database of standard building components;
   b) databases of geographical context and environmental restraints (GC&ER) at Province level.
2. Result database of the second phase:
   a) database of improved building components;
   b) database on thermodynamic simulation – has not been yet analysed;
   c) database of seismic dynamic simulation – has not been yet analysed.
3. Database of the third phase: has not been yet developed.

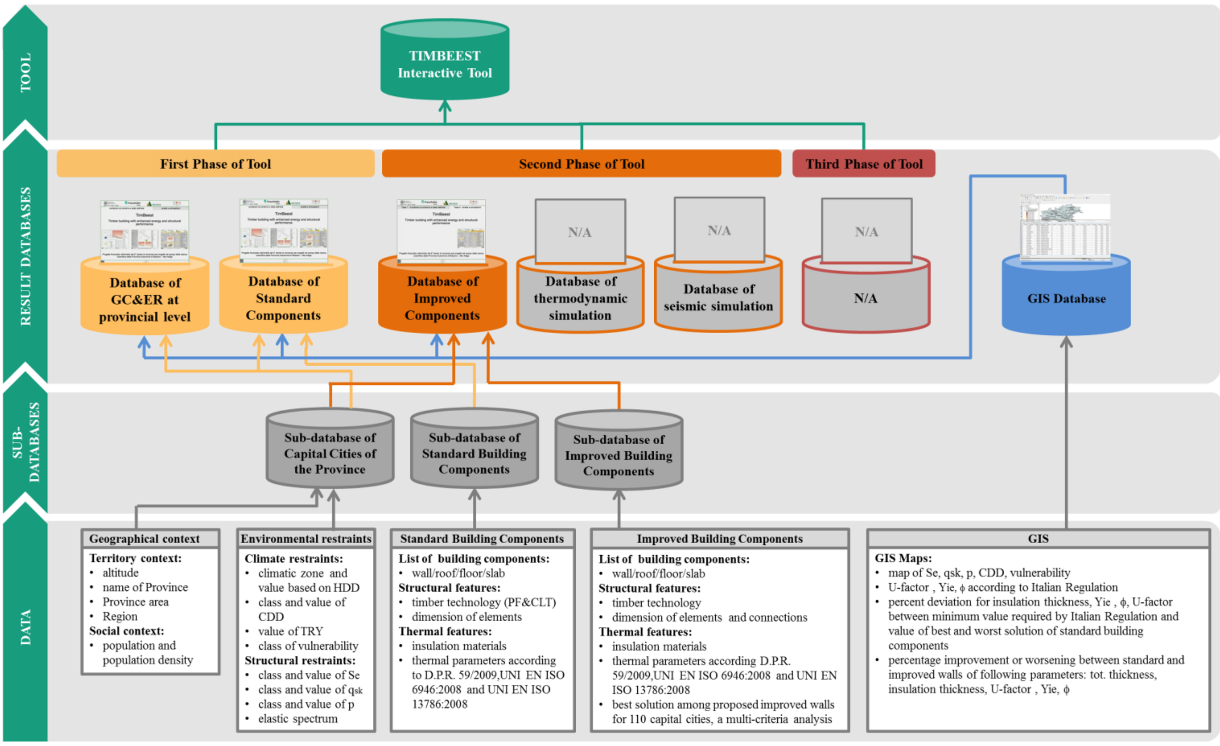

Figure 2 Flow chart of relations between sub-databases and result databases belonging to the first and second phase of TIMBEEST research project.

Because of the huge amount of data assigned to territory, the use of a GIS database is required to manage, analyse and visualize data as well as a GIS software **(Figure 3)** is needed to generate maps. The GIS database refers to the previously mentioned result databases.

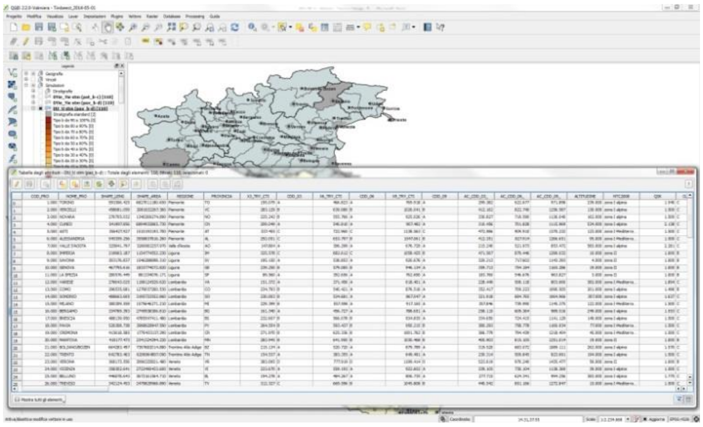

Figure 3 GIS database.

Considering the huge amount of data and interactions between them, the result databases is linked to different sub-databases in order to visualize data in one UI. The following sub-databases within the TIMBEEST interactive tool are presented: a) sub-database of capital cities; b) sub-database of standard building components; c) sub-database of improved building components.

The sub-database of capital cities (a) consists of geographical context data as: altitude, name of Regions, Provinces and capital cities, population number and population density of Provinces and capital cities; and environmental restraints data as: climatic zone based on Heating Degree Days, class and value of equivalent Cooling Degree Days, value of Test Reference Year, class and value of synthetic indicator, S_e, q_{sk}, and p. These environmental restraints data affect the thermal and structural performance of buildings.

Other two sub-databases (b and c) of standard and improved building components include information regarding type of building components and their structural and thermal features.

Result databases of the first phase

Figure 4 shows UI layout of the result database (1a), which is divided into topic area: 1) geographical context and environmental restraints; 2) building information; 3) structural features; 4) thermal features; 5) index of building components related to 110 capital cities of Italian Provinces. These information are visualized when a building component is selected from the index list.

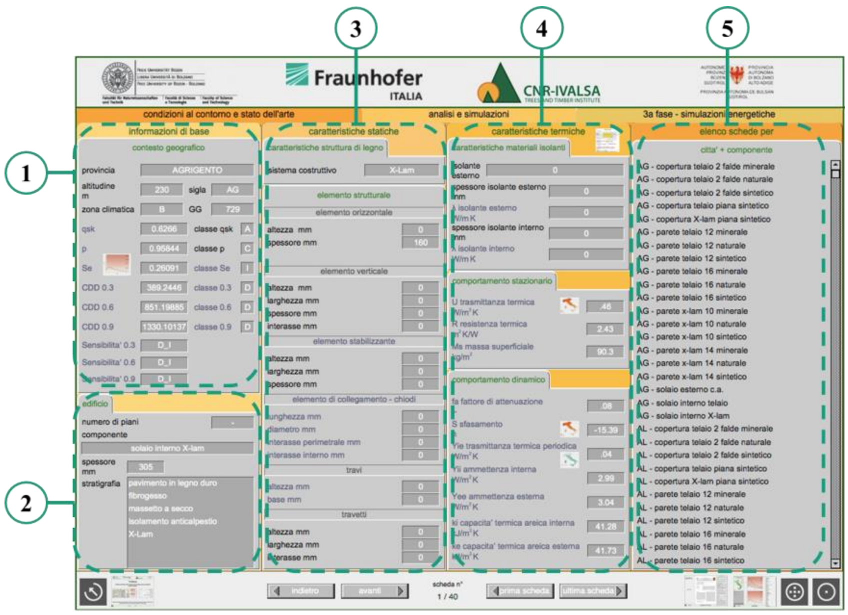

Figure 4 The UI layout of result database (1c) in the first phase of research project.

The first area regarding geographical context and environmental restraints **(Figure 4, point 1)** contains information and parameters related to capital cities such as: a) altitude; b) climatic zones and value based on HDD according to D.P.R. n. 412 26/08/93; c) class and value of snow load according to NTC 2008; d) class and value of wind load according to NTC 2008; e) class and value of horizontal elastic response spectrum according to NTC 2008; f) class and value of CDD referred to three different horizontal surfaces with absorption coefficient value (α, [-]) respectively 0,3, 0,6 and 0,9; g) class of synthesis referred to three absorption coefficient value. Furthermore, clicking on each parameter users can analyse GIS maps of Italian territory regarding q_{sk}. p, S_e, CDD and synthesis, which are structured as shown in **Figure 5a**: 1) GIS map with a legend and 2) description of parameter. The GIS maps are important to characterized territory and identify critical areas, for instance: the synthesis map allows highlighting the critical areas, affected by risks of overheating and earthquake.

Beside the seismic parameter Se a link to the GC&ER result database (1b) is integrated. **Figure 5 b** shows this result database, which provides information on: 1) map of seismic danger of the Italian territory evaluated under specific hypothesis by Istituto Nazionale di Geotecnica e Vulcanologia; 2) GIS map of related Region and the provincial classification of S_e; 3) graph of elastic spectrum, referred to capital city of the selected Province 4) graph of elastic spectrum with all capital cites presented in selected Region; and 5) environmental restraints – S_e class and value. The graph of elastic spectrum is elaborated using Simqke software developed by the University of Brescia.

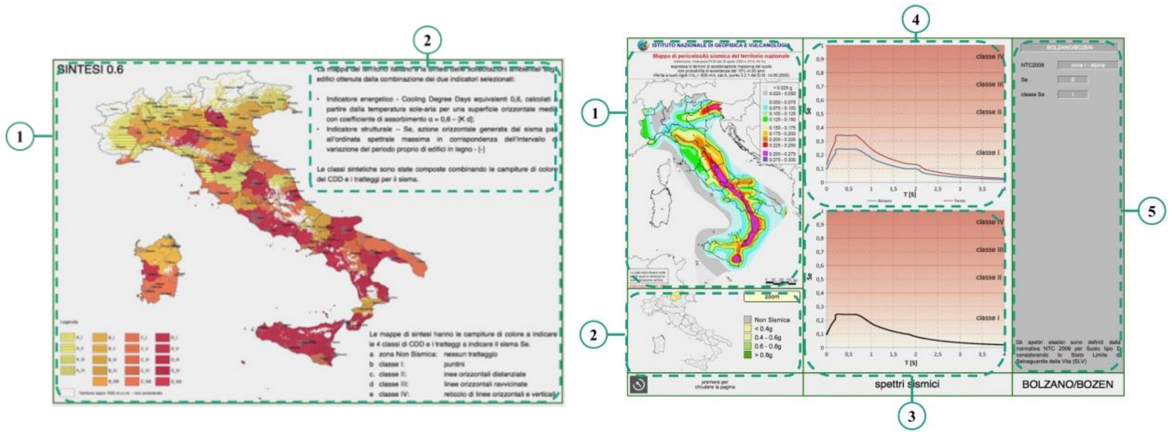

Figure 5 (a) The UI layout of the database of geographical context and environmental restraints at Province level; (b) Synthesis map.

The second area is dedicated to building information (**Figure 4, point 2**) and shows details regarding building components such as type of component (wall/roof/floor) in different technology PF and CLT, total thickness of component and list of layer composition. To enhance a comprehension of building component composition, the 2D drawings are visualized by clicking on text.

The third area is focused on structural features **(Figure 4, point 3)** and it is arranged in three parts: a) type of timber technology of selected building component; b) information regarding structural dimension of elements; and c) structural connections. Selecting building component from index list, the following information are provide for structural dimensioning: a) height and thickness of horizontal components; b) height, width, thickness and distance between elements (in case of PF) of vertical components; c) height, width and thickness for wall sheathing; d) length, diameter, and centreline spacing of screw connection; e) dimension of beams and studs. Furthermore, details regarding angle brackets, hold-down and screw connection for the following connection are specified: wall-to-concrete slab, wall-to-floor, wall-to-wall and beam-to-wall.

The fourth area presents thermal features **(Figure 4, point 4)** and provides the following data: a) thermal conductivity (λ, [W m^{-1} K^{-1}]) and thickness of different insulation materials (natural, mineral and synthetic) used in building component; b) thermal parameters, which are verified according to D.P.R. 59/2009 and UNI EN ISO 6946:2008 such as thermal transmittance (U-factor, [W m^{-2} K^{-1}]), thermal resistance (R, [m^{2} K W^{-1}]) and mass of component (Ms, [kg m^{-2}]); c) thermal parameters used for dynamic evaluation and verified according to UNI EN ISO 13786:2008 such as decrement factor (f, [-]), periodic thermal transmittance (Y_{ie}, [W m^{-2} K^{-1}]), time shift (ϕ, [h]), periodic thermal transmittance on interior side (Y_{ii}, [W m^{-2} K^{-1}]), periodic thermal transmittance on external side (Y_{ee}, [W m^{-2} K^{-1}]), interior areal heat capacity (k_1, [kJ m^{-2} K^{-1}]) and external areal heat capacity (k_2, [kJ m^{-2} K^{-1}]).

The fifth part **(Figure 4, point 5)** shows the index list of all building components, which are organized by capital city of the Province and type of timber technology.

In the result database (1a) of the first phase, next to U-factor, Y_{ie} and ϕ parameters, GIS maps are linked in order to visualize the minimum value required by Italian codes (**Figure 6 a, point 1**). **Figure 6 a, point 2, 3** shows two maps, which express the percent deviation for each parameter between minimum value and value of best and worst solution of standard building components in order to provide a range of variation. Furthermore, evaluations of all thermal parameters according to UNI EN ISO 6946:2008 and UNI EN ISO 13786:2008 using spreadsheet are integrated in database.

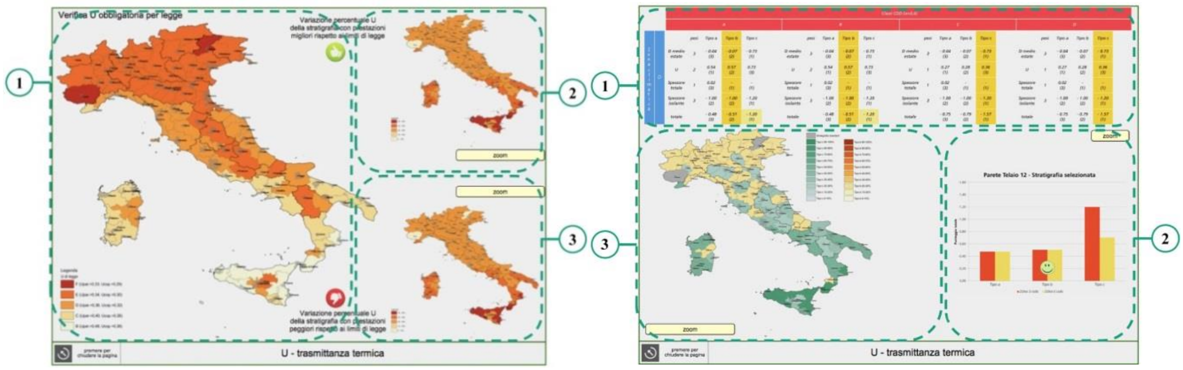

Figure 6 (a) GIS maps referred to thermal parameters; (b) GIS map referred to improved building components, and multi-criteria analyses.

Result database of the second phase

In the second part of research project improved solutions for building walls are studied. Four solutions for CLT technology and three solutions for PF technology are identified. The structure of the result database is the same of the (1a) one but the inserted data refer to other components. In order to find out the best solution for 110 capital cities among proposed ones, multi-criteria analysis is developed (**Figure 6 b, point 1, 2**). In order to combine the percentage improvement/worsening between best solution of standard and improved walls, the GIS database is used. This information are included into the result database (2a) of the second phase just next to thickness of insulation material, total thickness of the building component, the U-factor, the Y_{ie} and the ϕ (**Figure 6 b, point 3**). The layout of **Figure 6 b** allows having an overview of the best solution identified and its improvement or worsening through Italian territory. Furthermore, evaluations of all thermal parameters according to UNI EN ISO 6946:2008 and UNI EN ISO 13786:2008 using spreadsheet and comparison evaluation between improved solutions are integrated in this result database.

CONCLUSION

This research paper describes the structure of the TIMBEEST interactive tool. Since the research project is an on-going research till the first half of the year 2015, the database presented is not completed and is going to be continuously updated. Thereafter, the results of dynamic and structural dynamic simulation will be integrated in the database of the second phase in order to evaluate the percentage of gained improvement in structural and energy fields. Further steps will determine the environmental footprint of the improved building components to highlight the most sustainable solution towards the improvement of timber building performance during the cooling season. Beyond this information, the database of third phase should be developed entirely and it will aim at summing-up the research results.

The TIMBEEST interactive tool proved to be a useful support during different steps of research project. Data collected in various databases, but managed by one UI will allow researchers and professionals to manage and evaluate correctly and quickly the timber building components both from energy and from seismic point of view across the Italian territory during the design phase. Furthermore, considering future development of the project, researchers, who will be in charge of the development of new contents, can easily consult output data and even implement them. Such tool is used also as a controlling tool in order to check possible errors because of huge amount of data and intersection between them. Since the GIS software allows visualising data in the form of maps, errors are immediately highlighted in order to improve research methodology.

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UNI EN ISO 6946:2008 – Componenti ed elementi per edilizia - Resistenza termica e trasmittanza termica - Metodo di calcolo.

Session 5C : User behavior, thermal comfort & energy performance

PLEA2014: Day 2, Wednesday, December 17
11:30 - 13:10, Grace - Knowledge Consortium of Gujarat

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The use of Environmental Controls: Bioclimatic Performance of "Baixa Pombalina's" Heritage Buildings.

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ABSTRACT

"Baixa Pombalina", the downtown and historic district of Lisbon is one of the most important pieces of urbanism and architecture ever built in Portugal, and is at present time a UNESCO World Heritage nominate. Those Buildings were built after the great earthquake of 1755, for housing, commercial, and services` functions. And they constitute a rational and functional approach for health and comfort to their residents, translating the state-of-the-art of architecture at the time, through the use of lighting and natural ventilation. In this research study, buildings of "Baixa" are observed as a scenario where residents of 21st Century live in spatial and built structures of 18th Century. This paper is about environmental controls within current thermal and lighting performance of "Baixa Pombalina" Buildings. It analyses the efficacy of those buildings from the passive design point of view, as well as the habits of its occupants in controlling and regulating the devices available in "Baixa" buildings at present time. A questionnaire model was developed to study bioclimatic performance of offices, and residences selected in "Baixa". And field work involved a survey where workers of fifteen offices and residents of five houses have participated. Results demonstrate that in buildings of Baixa, controls are used less interactively during winter season and more interactively during summer season. Results indicate that in the Lisbon climate, it is mainly during the summer season that controls have a major role in thermal performance of these inheritage buildings.

Keywords: Baixa Pombalina, Building Performance, Environmental Controls, Comfort and Occupancy.

INTRODUCTION

This Paper analyzes actions of control by current users in buildings of "Baixa Pombalina", which are inheritage buildings built in the 18th Century. The goal of this study is to understand these buildings and their diversed systems in the context of current habits of usage and control.

According to a current notion of Sustainability, construction shall ensure bioclimatic and global human comfort, in buildings and urban spaces; sustainable use of construction materials and environmental technologies in buildings (Pinheiro, 2006). The project and work of "Baixa Pombalina" fall in many contemporary concepts of sustainability. When Baixa buildings were designed, in the 18th Century, lighting, heating and cooling were essentially provided by natural light and ventilation. These buildings were built in a time before the use of mechanical lighting and HVAC systems, and are therefore Architecture with capability to ensure energy efficiency. However, during 20th Century, occupancy density was increased and HVAC mechanical devices were introduced, changing the thermal performance of buildings, and the actions and habits of its users before the available controls.

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This Paper provides an overview of actions taken by users: with regard to the use of controls introduced in these buildings, e.g. mechanical devices, as well as actions to use the original controls of these buildings, e.g. windows to regulate natural ventilation.

URBAN AND ARCHITECTURAL CONTEXT

"Baixa Pombalina" is located in the historic city center of Lisbon, near "Tejo" River and between hills. After the Great Earthquake of 1755, the area was rebuilt according to the 1758 Plan. And their buildings are called "Pombalino Yield Buildings" ("Prédio de Rendimento Pombalino"), and have similar architectural features and are grouped into blocks.

Figure 1 *(a) View of "Pombalino" Buildings of Baixa and (b) Aerial view of "Pombalino" blocks and (c) View from inside the inner yards of Baixa (photos: author).*

The block improves buildings' salubrity with wider spaces between buildings in order to ventilate and to illuminate. The use of the shape of rectangular block allowed two fronts separated by an inner yard, and also, a large perimeter of the façade. Blocks are of two types: The first are arranged longitudinally with the axis in the direction North-South, and occupy most part of the urban grid. The latter blocks are arranged transversely, with the axis in the direction East-West, in the Southern part of the Plan, interrupting the progression of secondary streets to Trade Square ("Praça do Comércio"). Directions have a torsion of 16,5º to the North axis, making the Southeast oriented façades differ in only 1º of the optimal benchmark tortion of 17,5º to the North axis, recommended by Olgyay (1963) for temperate climates.

An inner yard ("saguão") in the core of the block separates two rows of the lot. For reasons of salubrity, an inner yard was introduced in the block, three metres wide, allowing aeration by ventilation and natural lighting to the interior of buildings. The inclusion of the inner yard ("saguão") in the block allows a larger passive area, i.e., area that allows to be lit and naturally ventilated, according to the LT Method (Baker & Steemers, 2000).

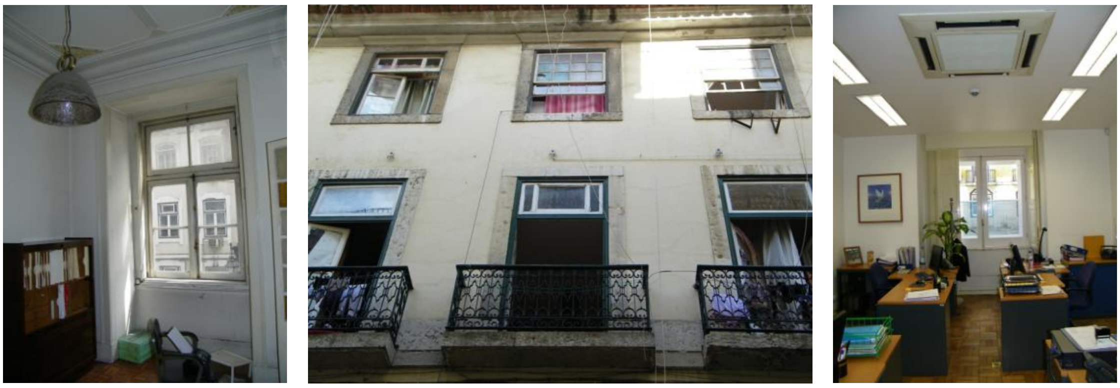
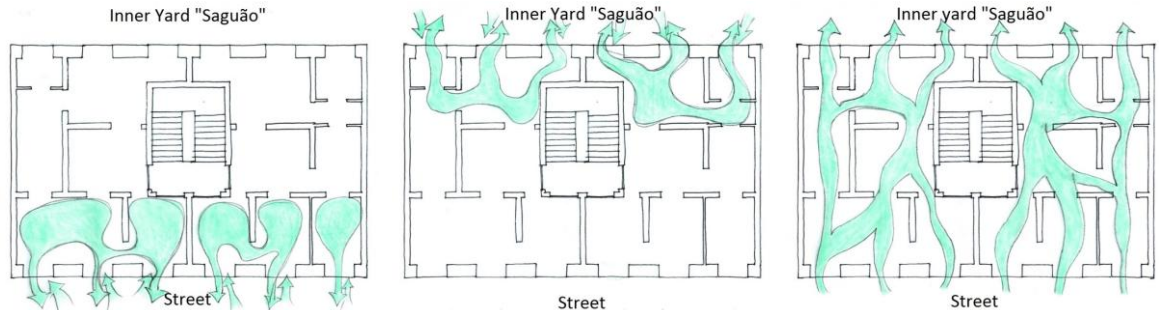


Figure 2 *(a) View of example of an exterior masonry wall and (b) Open windows of different types in a "Pombalino" building and (c) Example of the air conditioned system in offices in "Baixa" (source: author).*

In buildings of Baixa, the main construction elements responsible for thermal inertia are the exterior walls, due to its thickness, the weight, and due to the inherent coefficient of thermal storage. Consisting of stone masonry wall with lime mortar coating, with approx. 0,60m total thickness (Mascarenhas, 2004), **illustrated in Figure 2a**.

According to an analysis carried out from the available drawings (CML, 2005) the original windows were double-hung sash windows, which allowed a position of fixed aperture, and casement windows which had top-hung casement windows. Window types allowed to diversify the type of ventilation. These types of window are **exemplified in Figure 2b**.

In some residences and offices of Baixa, air conditioning devices were introduced. Air conditioning systems were usually introduced in spaces of small or medium sizes, where each space division has its own device, **exemplified in Figure 2c.**



a) b) c)

Figure 3 *(a) Scheme Plan of single-side ventilation that occurs with the windows open in the street façades and (b) scheme of single-side ventilation that occurs with the windows open in the inner yard ("saguão") façades and (c) scheme of cross ventilation that occurs with open windows in the street and inner yard ("saguão") façades (source: author).*

Baixa's interior units consist of a row of rooms with windows to the side of the street, and a row of rooms with windows to the side of the rear, to the inner yard ("saguão"). Thus, Baixa's buildings provide the possibility of having naturally ventilated rooms, in a varied way. Having windows on one side and the other allows various combinations: To open windows on the street side (only), on the rear side (only), or both. And it opens up possibilities of practicing various types of ventilation – single-side, cross, stack effect, as well as night-time ventilation, **as shown in Figure 3**. The ventilation strategy is a major bioclimatic strategy currently recommended for the Lisbon climate (Gonçalves & Graça, 2004).

THERMAL ENVIRONMENT

Lisbon has a unique variant of the typical Mediterranean climate due to its proximity to the Atlantic Ocean (Ribeiro, 1987). In the center of Lisbon, according to the climatic normal, the monthly average temperature in January is 11.0 ºC and in August is 22.3 °C. The minimum temperature is -2.8 ° C in February and the maximum temperature is 39.5 °C in July. In what regards to relative humidity (RH), the minimum value is 60% in August, and the maximum value is 87% in December (IM 1981).

The following chart of **Figure 4 shows** monitoring values registered with datalogger devices during a year, of a selected building, used as office, and representative of the thermal environment of "Pombalino Yield buildings". Results are presented according to the months of the year. The following chart is organized by data logger device that have registered indoor temperatures in a room with mechanical system off, simultaneously with outside temperatures.

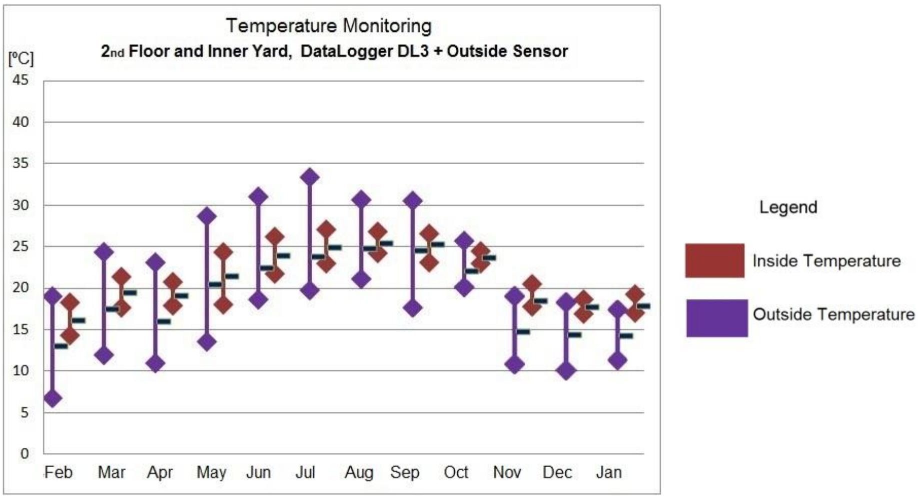


Figure 4 *Chart measuring averages, minimum and maximum temperatures registered in a room with mechanical system off, and outdoor spaces of the case study building.*

The previous graph in **Figure 4 shows** that when outside temperatures vary between 5ºC and 34,5ºC, indoor temperatures vary between 14ºC and 28ºC with the system off. It can be observed that during certain months of the year – from May to October - the average temperatures are within the range of 20ºC to 26ºC. - This means that during these months, average temperatures are within the limits of conventional comfort.

METHODOLOGY

A survey was conducted among subjects who live or work in Baixa, in Lisbon. The study was conducted in 20 fractions in 19 diverse buildings of Baixa, in housing and office spaces. Offices range from small private offices to large offices of Governmental Ministries and Institutes. 130 subjects were surveyed during the winter season, and 119 subjects were surveyed during the summer season, in a total of 249 subjects. 18 fractions were observed during each season of winter and summer of 2009. The variety of office and housing situations - in function, type of building, type of floor fraction, size, and location - is representative of the variety that exists in Baixa.

The evaluation was based on a survey, whose model was specifically developed for users of Baixa buildings, in Lisbon. The survey consists of a questionnaire to be answered based on their experience while users who live or work in those selected buildings.

In order to obtain an overview of actions of control applied by users, an analysis of frequency of actions applied by subjects surveyed was conducted, in what regards to:

1. Use of existing mechanical devices.
2. Opening windows, in duration, and spatial distribution.

And a comparison between the actions committed by users during the seasons of winter and summer was conducted.

In this sample, there is a higher percentage of respondents in the office function (95%) than in the residential function (5%). – Because there has been a greater availability from offices than by residences to participate in this study.

The study is focused on the use of windows and mechanical devices because those are the most used environmental controls that were observed in this study. Furthermore, currently most of Baixa's interior units have air conditioning. Although the use of shading devices was also observed during this research, this paper is focused on analyzing the use of windows and mechanical devices, being the main environmental controls used in buildings of Baixa at present time.

It was chosen to divide the study in winter and summer seasons, being the most representative of the opposite extreme situations that influence spaces during the year: Cold and dark compared to warm and bright climates.

DISCUSSION OF RESULTS

Heating and Cooling Mechanical Devices

The following **Tables 1 and 2 show** the frequency of periods of use of heating and cooling devices, in winter and summer seasons, respectively. Periods described correspond to a progression in time duration of use of mechanical devices.

Table 1. Frequency of Periods of Use of Heating Devices - Winter.

Periods	Frequency [%]
Never / NA	6,6 %
Punctually	9,9 %
Only on the coldest days	20,7 %
A few times per Winter	9,1 %
A few times per week	2,5 %
A few times per day	17,4 %
Almost always "on" during most of the Winter	33,9 %

Table 2. Frequency of Periods of Use of Cooling Devices - Summer.

Periods	Frequency [%]
Never / NA	2,6 %
Punctually	3,5 %
Only on the hottest days	9,6 %
A few times per Summer	2,6 %
A few times per week	1,8 %
A few times per day	25,4 %
Almost always "on" during most of the Summer	54,4 %

It can be observed in **Tables 1 and 2** that most of respondents turn on heating devices in Winter in the period "during most of the Winter", followed by "only on the coldest days". In summer, most of respondents turn on cooling devices in the period "during most of the summer", followed by "a few times per day".

Comparing both seasons, it can be observed that while in Winter the majority of respondents use the mechanical devices in the periods "almost always on" and exceptionally on ("only on the coldest days"), in Summer most of respondents use devices in periods "almost always on" and "a few times per day”, revealing the habit of having the cooling devices “on” during most of the Summer. Hence, one can conclude that the use of heating devices in winter presents different periods of use, depending on the type of building’s units. In a different way, in summer, the use of cooling devices is intensive, including AC devices (Air Conditioning devices, the most used), which are almost “on” during most of the season.

Natural Ventilation through opening of Windows

The following **Tables 3 and 4 show** the frequency of periods of opening windows, in winter and summer seasons, respectively. Periods described correspond to a progression in time duration of open windows.

Table 3. Frequency of Opening Windows in the Winter Season.

Period	Frequency [%]
Never	34,9 %
Punctually	43,7%
Morning / or Afternoon	13,5 %
Morning + Afternoon / or during the Night	6,3 %
Always	1,6 %

Table 4. Frequency of Opening Windows in the Summer Season.

Period	Frequency [%]
Never	16,4 %
Punctually	35,3%
Morning /or Afternoon /or Evening	21,6 %
Morning + Afternoon / or during the Night	21,6 %
Always	5,2 %

In Table 3, it can be observed that in the winter, the majority of subjects open windows “punctually” (43,7%) followed by “never” (34,9%). **In Table 4**, it can be observed that in the summer, the majority of subjects open windows “punctually” (35,3%) followed by isolated periods during the morning, or the afternoon, or in the evening (21,6%) or during all day or all night (21,6%). There are 16,4% of subjects that never open windows and 5,2% that has windows always opened.

The following **tables 5 and 6 show** the percentages of distribution of open windows, in winter and summer seasons, respectively.

Table 5. Distribution of Open Windows in Winter Season.

Distribution of Opening	During the Day	During the Night
Street and Rear	3,1 %	0 %
Only Street	44,1%	1,0%
Only Rear	12,6 %	1,0 %
No Opening	40,2 %	65,0 %
NA	0 %	33,0 %

Table 6. Distribution of Open Windows in Summer Season.

Distribution of Opening	During the Day	During the Night
Street and Rear simultaneously	13,9 %	2,9 %
Street and Rear alternate	7,8 %	1,0 %
Only Street	40,0 %	3,8 %
Only Rear	10,4 %	3,8 %
No Opening	26,1 %	45,2 %
NA	1,7 %	43,3 %

Table 5 shows that in the winter season, there is a large proportion of all subjects who does not open any window (40,2%). From those who open windows, most of subjects do it in the street side of their space (44,1%), followed by "only” in the rear side (12,6%). And it can be observed that subjects rarely open windows in the street and rear sides simultaneously (3,1%). A possible explanation is to prevent the drafts of cooling air and unwanted air in winter time.

It is observed in **Table 6** that in the summer, total of subjects open windows on street side primarily (40%), followed by "no opening" (26,1%) and "street and rear simultaneously" (13,9%). One possible explanation for the windows opening is to give rise to types of single-side ventilation or cross ventilation within the space allowing cooling and air renewal.

It is observed that generally, subjects do not open windows during the night in summer, which could be a strategy to cool the building fabric. This occurrence can be explained by the sample, which is mainly focused in the office function, where it has been observed that subjects do not leave windows open during the evening, i.e., outside working time. It has been described by subjects in residences that in summer, most of subjects have windows always open, during daytime and nighttime, as opposed to subjects in offices, that generally have windows open during daytime only.

These observed frequencies are partially explained by the widespread recurrence of mechanical devices, particularly during the summer season. This higher recurrence affects how windows are used. And to analyze these buildings' natural performance, it makes difficult to understand how the performance of these buildings would be without the use of mechanical appliances. One question that arises is whether if there were no air conditioning devices, how would be these buildings' use. And once not being able to use such devices, if there would be a more intensive use of other means that are available to regulate temperature, such as windows, shades or doors.

The observed use frequencies of mechanical appliances and windows can be explained by the sample, which is mainly focused in the office function and less in the residential function. The office function has a considerable density of occupancy and equipment producing internal heat gains, to which users respond turning on the mechanical appliances. This higher recurrence affects how the windows are used.

One can argue about the changing behavior of users of these buildings in the present context, where mechanical devices are available, as compared to the time when these buildings were constructed. Leads to formulate, as hypothesis, that users are not prepared to work with higher temperatures. Maybe because they are not used (anymore) to use all available controls: Users do not have a regular habit of opening windows. And in a simplified way, they are mainly restricted to the use of mechanical devices, neglecting the remaining environmental controls, such as windows or shading.

This complementarity of resources (natural + mechanical) is an important issue in the relationship between the regulation of mechanical equipment and windows. One may question whether this complementarity comes from compensation **-** triggered by the unnaturalness of mechanical controls, and one tries to compensate the thermal environment and air quality by opening windows, bringing natural air. Or one may ask if this complementarity is a correction **-** triggered by any fluctuation in temperature during the day, and while using mechanical controls, one tries to fix temperature by opening windows.

CONCLUSION

Regarding the thermal performance, it can be observed from analysis of the survey responses that generally:

1. Users turn on mechanical appliances in a greater frequency in summer than in winter;

2. Users open windows more often in summer than in winter.

3. Users open windows with greater distribution variety in the summer season than in the winter season.

After the analysis of results, it can be concluded about how buildings are used by users in each season:

4. In winter, subjects use less frequently heating devices, as well as the remaining elements to regulate temperature – They have a less interactive attitude - They use environmental controls to regulate temperature less frequently.

5. In summer, subjects use more frequently cooling devices, as well as the remaining elements to regulate temperature – They have a more interactive attitude – They use environmental controls to regulate temperature more frequently.

In winter, buildings of “Baixa”, in what regards to their controls are used less interactively. In this season, users use less frequently buildings’ original controls. And in the event of using controls, they use more frequently heating appliances. It must be noted that once, these buildings had fireplaces, that were meanwhile removed, and are now practically nonexistent. Over the years, the fireplace was replaced by heating devices.

In summer, architectural elements are used more interactively. In this season, most users use buildings’ original controls, such as windows. And users use more frequently cooling devices. It is observed that in summer, there is a greater effort than in winter, in using all means of temperature regulation available, such as windows. And in the event that users recur to air conditioning devices, they also use other controls to regulate temperature, such as opening windows (although it is not recommended to be used simultaneously because of conflict with AC). Architectural elements as a mean of temperature regulation are mainly used in the summer season. And it is an indication that under the climate of Lisbon, it is mostly in the summertime that controls have a greater role to play in these buildings in Baixa.

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Development of a Window Opening Algorithm to Predict Occupant Behavior in Japanese Houses

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ABSTRACT

We investigated window opening behaviour and the thermal environment over a period of more than 3 years in the living rooms and bedrooms of dwellings in the Kanto region of Japan. We collected over 32,000 data-samples from 243 residents of 121 homes. The proportion of 'open window' in the free running mode is significantly higher than that in the cooling and heating modes. The window opening is related to the indoor or outdoor air temperature. Window opening behaviour as predicted by logistic regression analysis is in agreement with the measured data. These findings can be applied to develop an adaptive algorithm for window opening behaviour in Japanese residences.

INTRODUCTION

Natural ventilation from opening windows has been decreasing in houses in recent years because of the increasing prevalence of mechanical ventilation and air-conditioning. However, temperature control by opening and closing windows can reduce environmental impact by minimizing the period of the year when air-conditioning is needed.

There has been more research into window-opening behaviour in offices (Rijal et al. 2007~2012, Yun & Steemers 2007, Robinson & Haldi 2008, Kim et al. 2009, Haldi & Robinson 2010) and university buildings (Suzuki et al. 2002, Umemiya & Yoshida 2004) than in dwellings (Dick & Thomas 1951, Asawa et al. 2005, Kubota 2007, Rijal et al. 2013). The findings from research in offices and universities cannot be assumed to apply to dwellings, where people's behaviour is less constrained. There is evidence that people respond differently in their own homes for a number of reasons, social, economic and cultural (Oseland, 1995). Thus it was necessary to conduct research also on residential window opening behaviour.

To explore window opening behavior and develop a window opening algorithm for Japanese residences, thermal measurements were made and an occupant behavior surveys conducted over a period of more than 3 years in the living rooms and bedrooms of dwellings in the Kanto region of Japan.

METHODOLOGY

Thermal comfort surveys and thermal measurements were conducted in 121 houses in Kanto region (Kanagawa, Tokyo, Saitama and Chiba) of Japan from 2010 to 2013 (Table 1). The detail of surveys 1, 2

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and 4 can be found in Rijal & Yoshimura (2011), Katsuno et al. (2012) and Rijal et al. (2014) respectively.

Indoor air temperature and relative humidity were measured in the living rooms and bedrooms, away from direct sunlight, at ten minute intervals using a data logger (Fig. 1). The globe temperature was also measured in the living room in surveys 3, 4 & 5. Outdoor air temperature and relative humidity were obtained from the nearest meteorological station.

The number of subjects was 119 males and 124 females. Respondents completed the questionnaire several times a day in the living rooms and twice in the bedrooms ("before go to bed" and "after wake-up from the bed") (Table 2). The thermal comfort survey was conducted several times a day using seven-point thermal sensation scales (Table 2). The window opening behaviour was recorded in binary form (0 = window closed, 1 = window open). We have collected over 32,000 samples.

Table 1. Description of survey

Survey	Survey period		Surveyed room	Measured variables*	Number of houses	Number of subjects			Number of votes	
	Start date	End date				Male	Female	Total	Living room	Bedroom
1	06-7-2010	18-7-2011	Living, Bed	T_i, RH_i	11	16	14	30	3299	2558
2	05-8-2011	06-9-2011	Living	T_i, RH_i	55	52	57	109	2819	-
3	21-7-2011	08-5-2012	Living, Bed	T_i, RH_i, T_g	14	11	12	23	463	984
4	25-7-2012	24-6-2013	Living, Bed	T_i, RH_i, T_g	30	26	28	54	13083	7061
5	10-8-2013	03-10-2013	Living, Bed	T_i, RH_i, T_g	11	14	13	27	936	1265

T_i: Indoor air temperature (°C), RH_i: Indoor relative humidity (%), T_g: Indoor globe temperature (°C), *: T_g is measured only in the living room.

Figure 1 Details of the thermal measurement

Table 2. Thermal sensation scale

No.	Now, how do you feel the air temperature?
1	Very cold
2	Cold
3	Slightly cold
4	Neutral (neither cold nor hot)
5	Slightly hot
6	Hot
7	Very hot

RESULTS AND DISCUSSION

3.1 Distribution of indoor and outdoor temperatures during voting

Table 3 shows the mean and standard deviation of the indoor and outdoor air temperature in each mode. Fig. 2 shows the monthly mean outdoor and indoor air temperature in FR mode in living room and bedroom. The mean outdoor air temperatures during the voting were 19.5 °C, 27.6 °C and 7.2 °C for FR, CL and HT modes respectively (Fig. 2). The mean indoor air temperatures at the time of voting were 24.2 °C, 27.3 °C and 19.2 °C for FR, CL and HT modes respectively. The Japanese government recommends the indoor temperature settings of 20 °C in winter

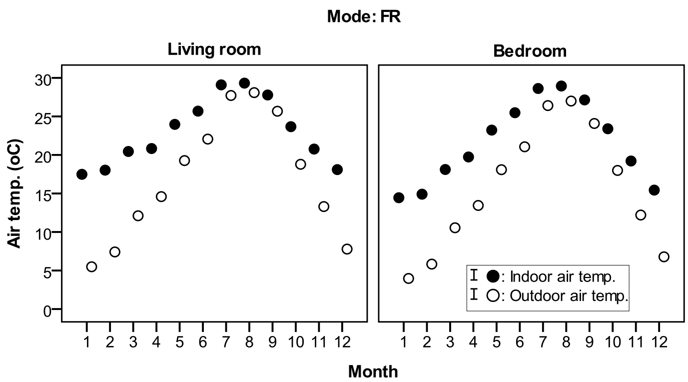

Figure 2 Monthly mean outdoor and indoor air temperature in FR mode.

and 28 °C in summer respectively. The results showed that the mean indoor temperatures during heating and cooling were close to the recommendation. The mean indoor and outdoor temperature difference was 4.7 K, -0.3 K and 12.0 K for FR, CL and HT modes respectively. The results show that the seasonal difference of the indoor air temperature is quite large, and that the data represent a wide range of outdoor temperature.

Table 3 Indoor air temperature and proportion of open windows in various modes

Mode	Room	Outdoor air temp. (°C)			Indoor air temp. (°C)			Window opening		
		N	Mean	SD	N	Mean	SD	N	Mean	SD
FR	Living	13,454	20.4	7.7	13,361	24.8	4.5	13,452	0.46	0.50
	Bed	9,054	18.2	8.0	9,000	23.3	5.6	9,110	0.30	0.46
	All	22,508	19.5	7.9	22,361	24.2	5.0	22,562	0.39	0.49
CL	All	6,677	27.6	2.7	6,407	27.3	2.0	6,648	0.03	0.16
HT	All	2,982	7.2	4.2	2,960	19.2	2.9	3,050	0.00	0.03

N: Number of observation, SD: Standard deviation

3.2 Evaluation of window opening behaviour

3.2.1 Status of window opening (WO)

To understand the window opening behaviour, the mean proportions of ‘window opening (WO)’ are compared. Table 3 shows the mean and standard deviation of the windows open in each mode. The mean WO is 0.39, 0.03 and 0.00 for FR, CL and HT modes respectively. The mean window opening in living room is higher than in the bedroom (Table 3). Interestingly, the mean WO in UK office buildings was 0.70 in NV mode and 0.04 in AC mode (Rijal et al. 2007). The mean window opening in Pakistan office and commercial buildings was 0.33 in NV mode. The results showed that the mean windows open is close to the Pakistan value and lower than the UK value. We shall limit the analysis to the FR mode.

Season, month and time of the day

Seasonal and monthly difference in proportion of windows open in FR mode is shown in Fig. 3. The proportion of open windows (WO) is highest in summer and lowest in winter. The WO in autumn is significantly higher than that in spring. This is possibly due to the fact that people are more adapted in spring to the winter low temperature, and in autumn to the summer temperature. In reality, the indoor and outdoor air temperatures in autumn are higher than in the spring (Fig. 3(b)).

Evidently, the proportion of open windows gradually increases towards the summer months (Fig. 3(c)). Conversely, it gently decreases towards the winter months as indoor or outdoor air temperature varies (Figs. 2).

The data were divided into four groups, in ascending order of time. Interestingly, the proportion of open windows gradually increases during the morning, and then decreases towards the evening (Fig. 4(a)). Most of occupants open the windows in the morning and shut them at night. These trends are similar for all seasons (Fig. 4(b)).

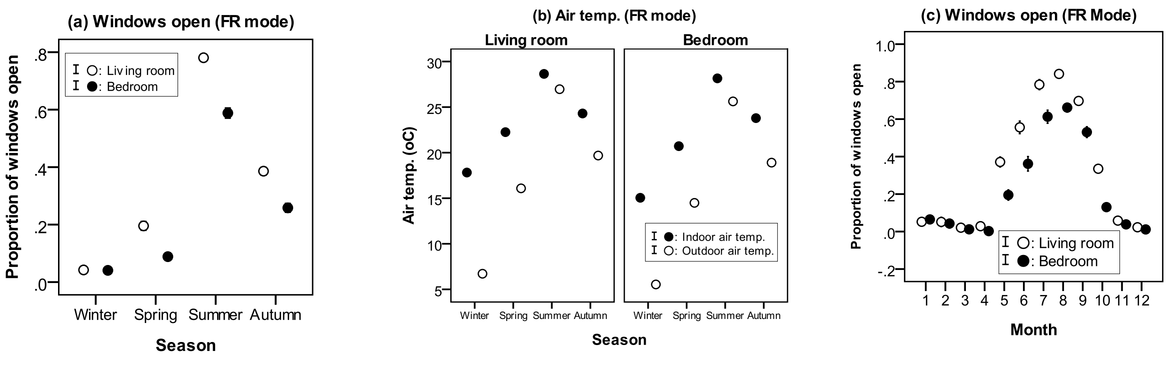

Figure 3 The proportion of open windows, indoor and outdoor air temperature (at 95% confidence level)

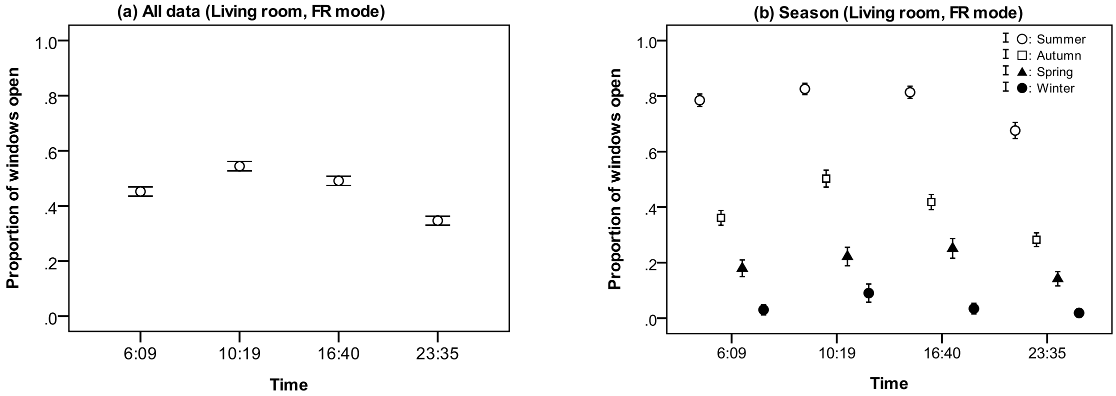

Figure 4 Proportion of open windows at 95% confidence intervals of time of day in living room.

3.2.3 Relationship between the open windows and air temperature

In FR mode the open window correlated better with the outdoor temperature than with the indoor temperature (Table 4). The correlation coefficient for the living room is higher than for the bedroom. From these observations, it can be inferred that the window opening is related to both indoor and outdoor air temperatures.

Fig. 5 shows the proportion of open windows and the corresponding temperatures. The data were divided into ten groups, in an ascending order of temperature. The proportion of the window opening rises as the indoor globe or outdoor air temperature rises. The proportion of window opening in the livingrooms is higer than in the bedrooms. When mean indoor air temperature is 27.1 °C, the proportion of open windows is 0.63 in living room and 0.51 in bedroom (Fig. 5(a)).

When the mean outdoor air temperature is 24.3 °C, the proportion of windows open is 0.71 in livingrooms and 0.58 in the bedrooms (Fig. 5(c)). These proportions are similar to the Pakistan study (Rijal et al. 2008), and significantly lower than that of the UK study (Rijal et al. 2007). This is perhaps because the indoor and outdoor air temperature in Japan and Pakistan are condiderably higher than that in the UK.

Table 4. Correlation coefficients in FR mode

Room	Items	Window: T_i	Window: To	T_i: T_o
Liivingroom	Correlation coefficient (r)	0.58	0.62	0.87
	Number of samples (N)	13,289	13,382	13,352
Bedroom	Correlation coefficient (r)	0.46	0.50	0.89
	Number of samples (N)	8,946	9,000	8,997
All	Correlation coefficient (r)	0.53	0.58	0.88
	Number of samples (N)	22,235	22,382	22,349

T_i: Indoor air temperature (°C), T_o: Outdoor air temperature (°C) All correlations are significant (p<0.001)

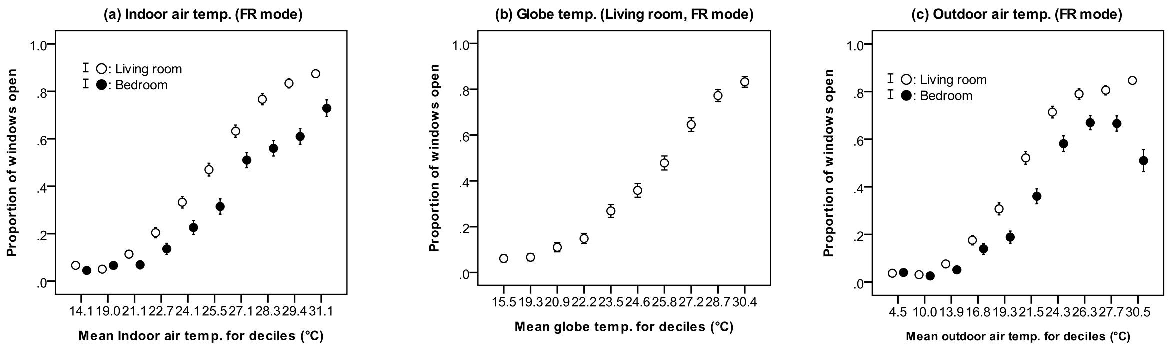

Figure 5 Proportion of open windows with 95% confidence intervals at deciles of temperatures.

3.3 Potential of the open window

3.3.1 Indoor air temperature

Fig. 6 and Table 5 show the seasonal variation in indoor air temperature for cases when windows are open and closed. The mean indoor air temperature for the window open condition is 27.7 °C in the livingroom which is significantly higher by 5.3 K, than for the window closed condition. In UK office buildings, the mean globe temperature for the window open condition is 23.4 °C which is 1.2 K higher than when the window is closed (Rijal et al. 2008a). Thus, the temperature difference between the cases of open and closed window in residential buildings is higher than that of the office buildings. The temperature difference is highest in autumn. In winter, the mean indoor air temperature for the 'open window' case is significantly lower than that of the 'closed window' case. The results showed that window opening is an effective way to control the indoor thermal environment.

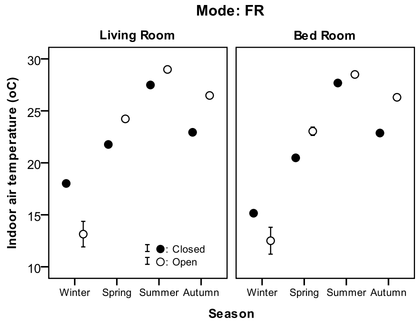

Figure 6 Seasonal variation of indoor air temperature for windows open and closed in FR mode.

Table 5. Indoor air temperature for windows open and closed

Season	Window	Indoor air temperature T_i (°C)									
		Living room					Bedroom				
		N	Mean	SD	t*	Open-Closed	N	Mean	SD	t*	Open-Closed
Winter	Closed	1,247	18.0	3.2	10.8	-4.9	1,261	15.2	4.3	4.4	-2.6
	Open	55	13.1	4.5			54	12.5	4.7		
Spring	Closed	2,025	21.8	2.6	-19.2	2.5	1,631	20.5	3.6	-8.9	2.6
	Open	493	24.2	2.2			165	23.0	2.6		
Summer	Closed	1,038	27.5	2.4	-19.0	1.5	1,182	27.7	2.3	-10.0	0.8
	Open	3,685	29.0	2.2			1,675	28.5	2.1		
Autumn	Closed	2,926	22.9	3.3	-37.1	3.5	2,198	22.9	3.8	-22.3	3.4
	Open	1,820	26.5	3.0			780	26.3	3.3		
All	Closed	7,236	22.4	4.0	-82.1	5.3	6,272	21.6	5.4	-48.8	5.6
	Open	6,053	27.7	3.3			2,674	27.2	3.7		

*All open/closed temperature differences are statistically significant ($p<0.001$)

3.3.2 Comfort temperature

The potential of the open window is further analyzed in the context of comfort temperature. The comfort temperatures were obtained by the Griffiths' method (Griffiths 1990, Nicol et al. 1994, Rijal et al. 2008, Humphreys et al. 2013, Rijal et al. 2014).

$$T_c = T_i + (4 - C) / a^* \quad (1)$$

T_c is the comfort temperature by Griffiths' method (°C), T_i is the indoor air temperature (°C) and a* is the regression coefficient (=0.50).

Fig. 7 and Table 6 show the seasonal variation in comfort temperature with windows open and closed. The mean comfort temperature for window open is 26.5 °C in living room which is 3.7 K higher than that of the case of window closed. Brager et al. (2004) found 1.5 K higher comfort temperature for the people with an access to window operation than the group

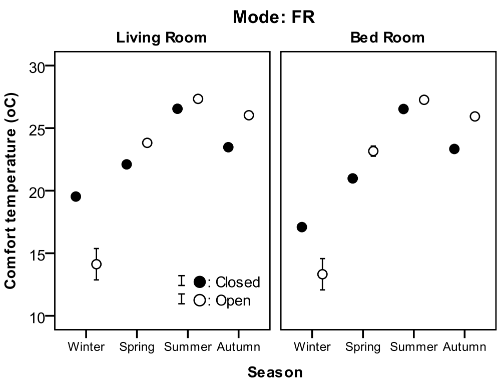

Figure 7 Seasonal variation of comfort temperature for windows open and closed in FR mode.

without in office buildings. The temperature difference is highest in autumn. In winter the mean comfort temperature for the open window condition is significantly lower than for the window closed condition. The results showed that window opening is effective to create the comfortable thermal environment.

Table 6. Comfort temperature for windows open and closed

Season	Window	Comfort temperature T_c (°C)									
		Living room					Bedroom				
		N	Mean	SD	t-value*	Open-Closed	N	Mean	SD	t-value*	Open-Closed
Winter	Closed	1,247	19.5	2.6	14.6	-5.4	1,260	17.1	3.8	7.1	-3.8
	Open	55	14.1	4.6			54	13.3	4.6		
Spring	Closed	2,025	22.1	2.3	-14.9	1.7	1,631	21.0	3.3	-8.1	2.2
	Open	492	23.8	2.2			165	23.2	2.6		
Summer	Closed	1,038	26.5	2.1	-10.8	0.8	1,179	26.5	2.2	-9.5	0.7
	Open	3,683	27.3	2.1			1,675	27.3	2.0		
Autumn	Closed	2,926	23.5	2.8	-31.0	2.6	2,196	23.3	3.3	-19.2	2.6
	Open	1,819	26.0	2.6			779	25.9	2.9		
All	Closed	7,236	22.9	3.3	-69.1	3.7	6,266	22.1	4.5	-44.6	4.3
	Open	6,049	26.5	2.8			2,673	26.3	3.2		

*All open/closed temperature differences are statistically significant ($p<0.001$)

3.4 Development of an algorithm to predict window opening behaviour

3.4.1 Logistic regression curves

In the previous section, we analyzed the window opening behaviour based on field data and confirmed some general behavioural trends, but no attempt was made to predict the occupant behaviour in housing (Rijal et al. 2013). Such predictions are needed for the thermal simulation of buildings.

Nicol and Humphreys (2004) made use of Probit analysis to predict occupant control behaviour in NV buildings. For mathematical convenience they used a Logistic distribution in place of the Normal distribution. The relationship between the probability of windows open (p) and the indoor or outdoor temperature (T) is of the form:

$$\text{logit(p)} = \log \{p/(1–p)\} = bT + c \quad (2)$$

$$p = \exp^{(bT+c)}/\{1+\exp^{(bT+c)}\} \quad (3)$$

and where exp (exponential function) is the base of natural logarithm, b is the regression coefficient for T, and c the constant in the regression equation.

We have adopted the same method here, using SPSS version 19 for the calculations. The Logistic regression equations, based on the indoor or outdoor temperature, are shown in Fig. 8. The following regression equations were obtained in between the windows open and the indoor or outdoor air temperature:

Living room

$$\text{logit(p)}=0.394T_i - 10.144 \quad (n= 13,289, R^2=0.34, S.E.=0.007, p<0.001) \quad (4)$$

$$\text{logit(p)}=0.372T_g - 9.659 \quad (n=9,833, R^2=0.29, S.E.=0.008, p<0.001) \quad (5)$$

$$\text{logit(p)}=0.258T_o - 5.675 \quad (n=13,382, R^2=0.38, S.E.=0.004, p<0.001) \quad (6)$$

Bedroom

$$\text{logit(p)}=0.291T_i - 8.100 \quad (n=8,946, R^2=0.24, S.E.=0.008, p<0.001) \quad (7)$$

$$\text{logit(p)}=0.206T_o - 5.113 \quad (n=9,000, R^2=0.26, S.E.=0.005, p<0.001) \quad (8)$$

All data

$$\text{logit(p)}=0.349T_i - 9.235 \quad (n=22,235, R^2=0.30, S.E.=0.005, p<0.001) \quad (9)$$

$$\text{logit(p)}=0.238T_o - 5.466 \quad (n=22,382, R^2=0.34, S.E.=0.003, p<0.001) \quad (10)$$

T_i: Indoor air temperature (°C), T_g: Globe temperature (°C), T_o: Outdoor air temperature (°C), n:

sample size, S.E.: Standard error, *p*: Significance level of the regression coefficient, R^2: Cox and Snell R^2.

A regression coefficient of 0.349 is obtained when the indoor air temperature is the predictor. This is higher than that obtained when the outdoor air temperature is used. In the Gifu region of Japan (Rijal et al. 2013), regression coefficients of 0.248 and 0.210 respectively were obtained with indoor or outdoor temperature. In Pakistan (Rijal et al. 2008) and in UK (Rijal et al. 2007) studies, regression coefficients of 0.176 and 0.354 respectively were obtained with indoor globe temperature is the predictor. In Kyoto (Majima et al. 2007) and UK (Rijal et al. 2007) data returned the regression coefficients of 0.119 and 0.181 respectively with outdoor air temperature is the predictor. The regression coefficient in the living room is slightly higer than the bedroom. The predicted window opening is well matched with measured values (Fig. 8).

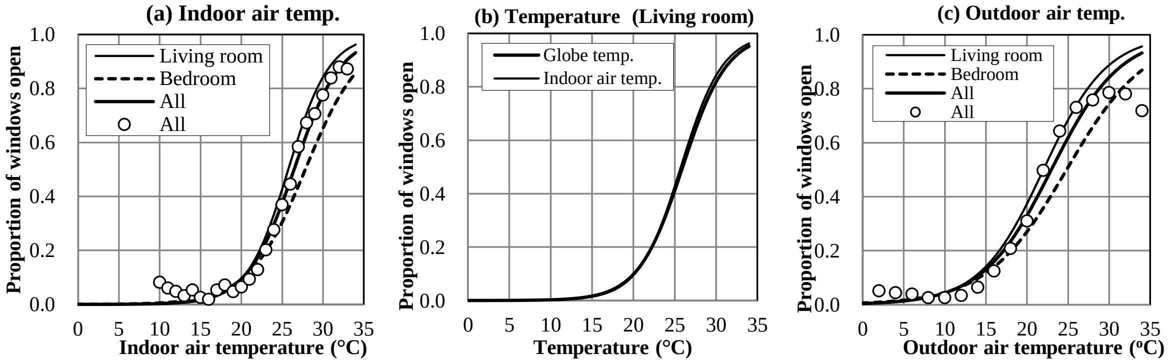

Figure 8 Comparison of measured (open circular dots) and predicted value (curved line) in NV mode. Measured values were grouped for every 1 °C for indoor air temperature and for every 2 °C for outdoor air temperature. The grouped data for samples less than 100 are not shown.

CONCLUSIONS

We have investigated the window opening behaviour and corresponding thermal environment over a period of more than 3 years in the living rooms and bedrooms of dwellings in the Kanto region of Japan and the following results were found:

1. The proportion of the window opening in the free running mode is significantly higher than that of the cooling or heating modes.
2. The window opening is related to the indoor and outdoor air temperature in the free running mode.
3. The window opening behaviour is predicted based on indoor and outdoor air temperature using logistic regression analysis. The predicted window opening matched well with that of the measured value.

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Determining the Trade-offs between Thermal Comfort and Cooling Consumption in Indian Office Buildings

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ABSTRACT

The present work is to understand the impact of setpoint temperature and coefficient of performance (COP) of a cooling system on cooling energy consumption, and its effect on thermal comfort of occupants in office spaces for the different climate zones of India. The occupants' thermal comfort sensation is addressed here by the PMV (Predicted Mean Vote) index. The investigation of the mutual relationship between thermal comfort and energy demand is of the foremost importance to define the benchmarks for calibrating the energy use in office buildings. The first approach of this study is associated with the thermal comfort optimization and the second strategy includes energy consumption minimization while maintaining adequate thermal comfort. Results from the parametric energy simulation of a typical open plan office building are presented for different cases in order to evaluate the results with variations in cooling setpoint temperature and COP (an indicator of chiller performance). The results indicate there is a scope to reduce cooling energy consumption without compromising thermal comfort. India has a wide range of climatic conditions, hence this research comes up with a comparative analysis of cooling energy savings per unit increase in the cooling setpoint temperature for different climatic zones based on the system efficiency. Looking at the total energy use, this study suggests, the appropriate modulations in the setpoint temperature with respect to its climate zone.

INTRODUCTION

Any building requires energy for many functions like construction, operation and demolition. The main sector for energy consumption is building operation, of which HVAC systems form the most important end-use (Mathews, Botha, Arndt, & Malan, 2001). Buildings consume 33% of total energy in India and this is growing at the rate of 8% per annum (Rawal et al., 2012). Estimates reveal that, total built-up area will increase rapidly, as nearly 66% of the commercial sector is yet to be built by 2030 (Ramesh & Khan, 2013). Energy efficiency in buildings is a critical issue due to the increase in energy costs, energy consumption and the related environmental impacts, especially those related to global warming.

It is therefore, important to realize the energy consumption while regulating the indoor temperature. In the past, the thermal comfort standards was not analysed to optimize energy efficiency (Indraganti & Rao, 2010).Thermal comfort has a significant impact on the productivity of building occupants and it is also important to consider energy consumption with it. Recently, the idea of comfort and good living has been re-defined completely and the building industry responded to this new comfort expectation with vigor. In the last two decades, there has been exceptional increase in demand for air conditioned buildings as perception of comfort is changing rapidly. A building may be designed or retrofitted with energy efficiency measures resulting in substantial energy bill savings. These savings show great loss with respect to workplace inefficiencies, if the occupants are not comfortable(Mathews et al., 2001).

Most published research work deals with common "quantifiable" factors such as temperature, humidity and air velocity etc. However, the state of comfort depends on a wide range of factors, which are "not quantifiable" such as mental status, habits, education of the people etc. Among these factors, the one that is most studied is "acclimatization" to a particular climate. Various studies confirm that preferences/ acclimatization of people in different locations vary. This may result in people of warmer climate having a tolerance to higher temperatures as compared with people in colder region (Corgnati, Fabrizio, & Filippi, 2008; Indraganti & Rao, 2010; Mallick, 1996). There is a need to define comfort range of setpoint temperature according to the context of region and ambient temperature(Indraganti & Rao, 2010).This study attempts to understand the impact of variation in cooling setpoint temperature and chiller coefficient of performance (COP) on energy consumption as well as thermal comfort of occupants in office spaces.

India is a vast country with a variety of geographical features resulting in a multitude of climatic conditions. These have been simplified and categorized into five climatezones – hot and dry, warm and humid, composite, moderate and cold. Detailed characteristics of these zones are provided in the National Building Code of India (Bureau of Indian Standards, 2005). For this study, one representative city from each of these climate zones was identified: Ahmedabad, Chennai, Delhi, Bangalore and Guwahati.

METHODOLOGY

For the purpose of this study, a typical office building was modeled in Design Builder 3.0.0.104 using input parameters obtained through literature study.Simulations were run for five climatic zones mentioned earlier and the roof and floor were treated as adiabatic representing a typical intermediate floor.

ACTIVITY DETAILS	
Occupancy details	0.01 people/m^{2}or 6.25 m^2/person
Metabolic rate	0.9 (typing)
Other gains: computer	11 W/m^2
Clothing for winter	1.0 Clo
Clothing for Summer	0.5 Clo
Lighting	
Target illuminance	500 lux
Default display lighting	11 W/m^2
CONSTRUCTION DETAILS	
Walls	230mm thick brick wall with 60 mm XPS polystyrene in outer surface
U-Value	0.440 W/m^2.K (as per ECBC)
Roof	Flat roof of 150mm in cast concrete with XPS polystyrene and Asphalt insulation on top surface
U-Value	0.409 W/m^2.K (as per ECBC)
OPENINGS	
WWR	30%
Window details	1500mm window height, 800mm sill height
GLAZING	

Glass	6mm Low E clear glass
U-Value and SHGC	1.65 $W/m^2.K$ and 0.293 respectively
Frames	UPVC frames
HVAC Details	
HVAC Type	PTAC (Packaged terminal air conditioner)
Cooling Setpoint temperature	Varies as per case (ranges between 22˚C to 28˚C)
Cooling system COP Values	Varies as per case (ranges between 2 to 5)

Considerations

Thermal comfort depends on four environmental factors – air temperature, mean radiant temperature, air velocity and relative humidity. For the purpose of this study, only air temperature is being varied for the purpose of simulation study and the other parameters are allowed to float as per the variation in temperature. Although the operative temperature thermostat AC system gives more significant results for PMV values, air temperature thermostat is used for this study so as to match it with the conventional practice carried out in India. PTAC system is considered for air conditioning. As this system specification does not allow the humidty to vary considerably at a given temperature. Also variation is too less to impact the PMV values.

Runchart: To understand the influences of setpoint temperature and COP values on thermal comfort and enegy consumption, a pathway or a methodology was planned to gain the required results:

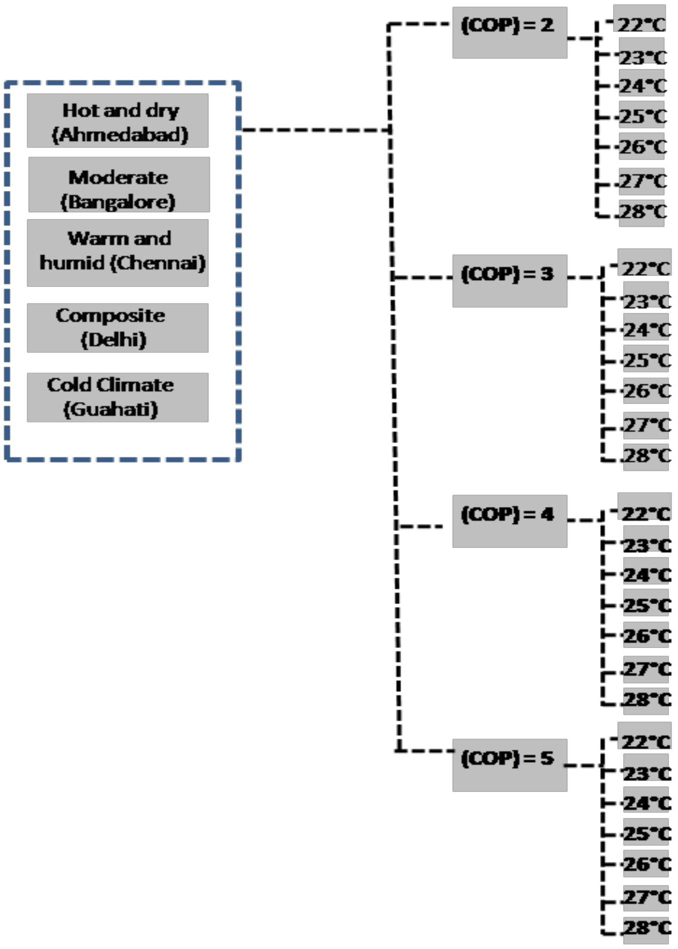

Figure 1 Run chart for simulations

It can be noticed that there are three major and intentional variables (outdoor temperature, COP values and setpoint temperature). For this study, two major outputs: cooling energy consumption and PMV index are analyzed that are obtained from design builder output data sheet.

RESULTS

To resolve the obtained results for comparission of each case, the cooling energy consumption is convertd into EPI (energy performance Index i.e. the ratio of total electricity used in a building to its total built up area. It is expressed as KWh/m^2/annum).

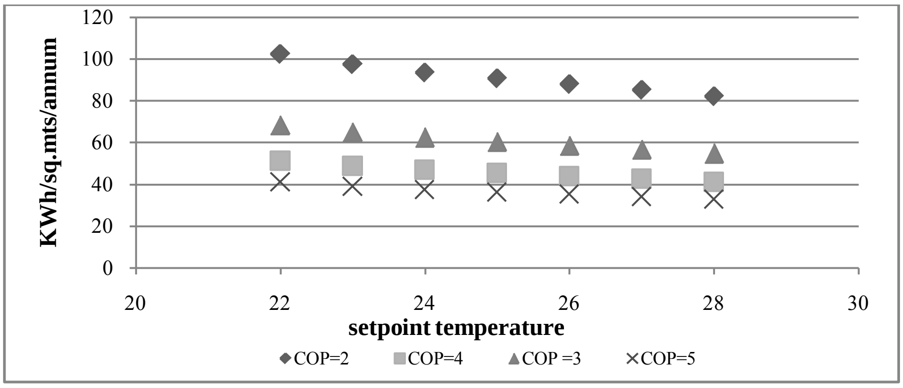

Figure2 *Energy Performance Index for Ahmedabad at particular COP value at Corresponding temperature*

Figure 2 Shows all cases are split into four distinct lines representing cooling energy on 2, 3, 4 and 5 COP value. The case with COP value 2 has the highest cooling enegy consumption and those with COP values 3 and 4 have the lower intermediate values and COP 5 being the lowest. Cooling consumption reduces as the COP value increases, however, this decrement varies drastically. Cooling energy consumption decreases significantly from COP 2 to 3 at particular temerature. The difference of almost 30 units (KWh/m^2/annum) is constant for each setpoint temperature for COP 2 and COP 3. The gradient slope for a single COP value having different setpoint temperature is steep till COP 3, and becomes gentler between COP 4 and the gradient line becomes almost straight for COP 5. This means that cooling consumption becomes nearly constant for higher COP value and there is not much net savings with increase in setpoint temperature. To quantify the same, there is a difference of 21 units of cooling consumption between setpoint 22˚C to 28˚C when COP is 2, however the difference get as low as only 8.0 units for setpoint temperature variations of COP value 5. So it is critical to decide the correct COP value as well for the desired setpoint temperature.

Table 1 EPI at particular Setpoint temperature and COP value for Ahmedabad

SETPOINT/COP	2	3	4	5
22˚C	**103**	68	51	41
23˚C	98	65	49	39
24˚C	94	62	47	37
25˚C	91	61	45	36
26˚C	88	59	44	35
27˚C	85	57	43	34
28˚C	82	55	41	**33**

The values in Table 1 show EPI (KWh/m^2/annum) at respective setpoint temperature and cooling system COP values. It can be seen that the EPI value decreases with increment in the cooling setpoint temperature as well as COP value. Maximum amount of cooling energy consumption per annum takes place at COP 2 and cooling setpoint of 22˚C. And the minimum cooling energy consumed annually for this case is 33 units, for COP 5 and setpoint 28˚C. There is also a reduction in cooling consumption of about 5.0 % annually with 1˚C increment in cooling setpoint. With an increase in COP value at the same setpoint, cooling consumption can be decreased substantially. It decreases by almost 30.0% when COP is changed from 2 to 3. However, chaging COP value from 4 to 5 leads to only 10.0% decrease.

Table 2 Percentage of hours falling under a given range of PMV value

SETPOINT/COP	-2.5	-1.5	-0.5	0.5	1.5	2.5	3
	-3	**-2.5**	**-1.5**	**-0.5**	**0.5**	**1.5**	**2.5**
22˚C	0%	0%	31%	62%	7%	0%	0%
23˚C	0%	0%	0%	70%	30%	0%	0%
24˚C	0%	0%	0%	45%	55%	0%	0%
25˚C	0%	0%	0%	44%	56%	0%	0%
26˚C	0%	0%	0%	1%	99%	0%	0%
27˚C	0%	0%	0%	0%	100%	0%	0%
28˚C	0%	0%	0%	0%	72%	28%	0%
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**

Table 2 gives the percentage of hours out of occupied hours falling under particular bin of PMV value at a given setpoint temperature. It shows that at 22˚C and 23˚C setpoint temperature gives more than 60 % hours having PMV value in a range of 0.5 to -0.5. i.e., more than 60% of the occupied hours are comfortable for the occupants. The percentage gets reduced to 45% at 24˚C. It can be noticed that no matter 26˚C or 27˚C is maintained as indoor temperature 100% of the occupied hours fall under PMV value 0.5 to 1.5 i.e. uncomfortable thermal conditions. Table 3 shows a comparative analysis of different climatic zones of India on how much one can save on each degree rise of setpoint temperature. The table can be used by the occupant to interpret at what temperature it will make sense to reduce or modulate the indoor temperature and how much one can save against it with respect to the climatic zone.

Table 3 Shows percentage of reduction in cooling energy consumption at corresponding temperature in particular cities

Ahmedabad	Bangalore	Chennai	Delhi	Guwahati
-	-	-	-	-
7%	7%	6%	7%	6%
7%	8%	6%	7%	6%
6%	7%	7%	7%	6%
8%	8%	8%	8%	8%
9%	9%	9%	8%	9%
10%	9%	10%	9%	10%

Figure3 gives an idea of percentage of people dissatisfied with their thermal environment at each setpoint temperature considered in each particular city, representing respective climatic zone.

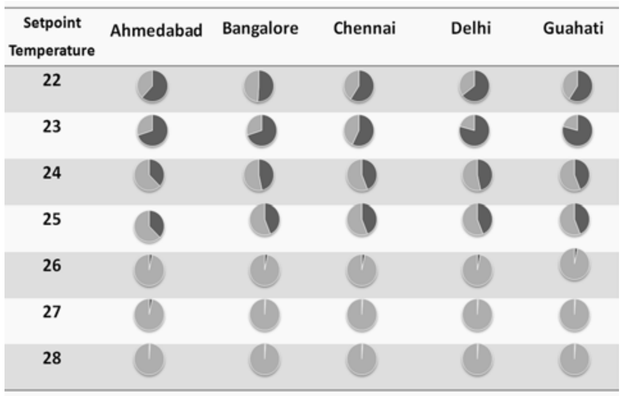

Figure 3 *Showing % of Comfortable Hours in black*

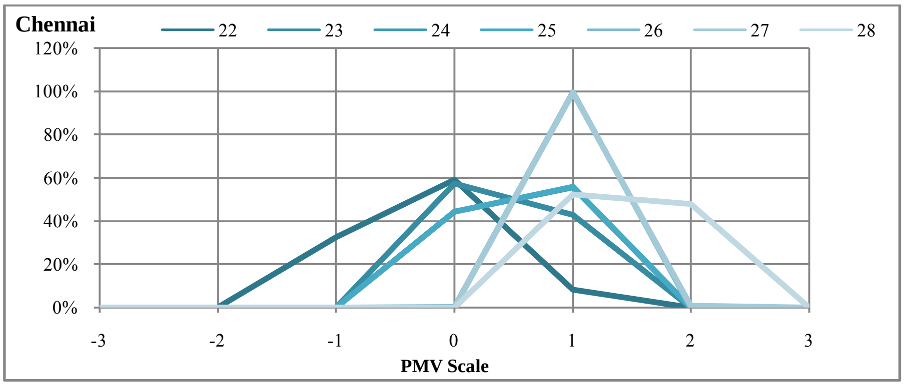

Figure 4 *Comfort conditions for Chennai at given setpoint temperatures*

Table 4 EPI at particular Setpoint temperature and COP value for Chennai

SETPOINT/COP	2	3	4	5
22˚C	**97**	65	49	39
23˚C	91	61	46	36
24˚C	85	57	43	34
25˚C	80	53	40	32
26˚C	74	49	37	29
27˚C	67	44	33	27
28˚C	60	40	30	**24**

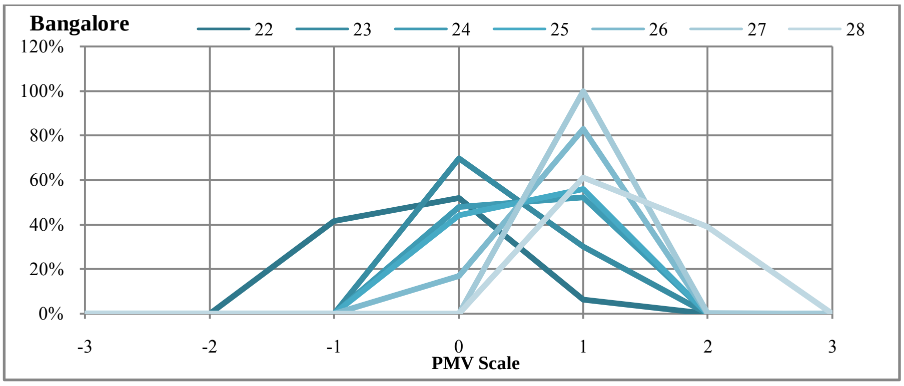

Figure 5 *Comfort conditions for Bangalore at given setpoint temperatures*

Table 5 EPI at particular Setpoint temperature and COP value for Bangalore

SETPOINT/COP	2	3	4	5
22˚C	**84**	56	42	34
23˚C	78	52	39	31
24˚C	72	48	36	29
25˚C	67	44	33	27
26˚C	61	41	31	24
27˚C	56	37	28	22
28˚C	50	34	25	**20**

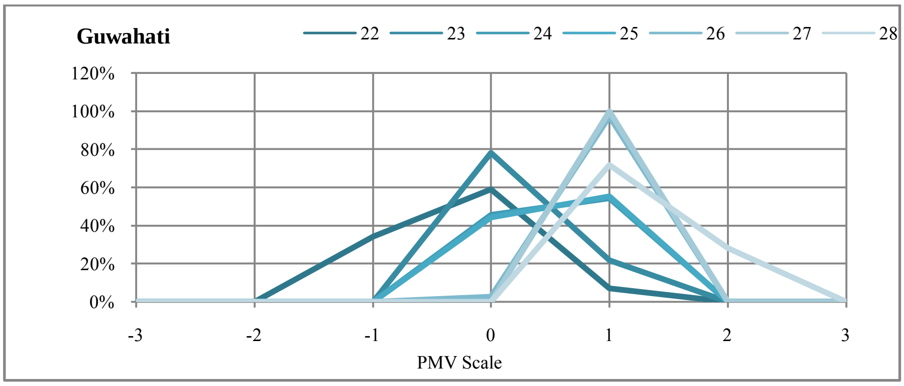

Figure 6 *Comfort conditions for Guwahati at given setpoint temperatures*

Table 6. EPI at particular Setpoint temperature and COP value for Guwahati

SETPOINT/COP	2	3	4	5
22˚C	**86**	57	37	30
23˚C	81	54	35	28
24˚C	76	51	33	27
25˚C	72	48	32	25
26˚C	66	44	29	24
27˚C	60	40	27	22
28˚C	54	36	25	**20**

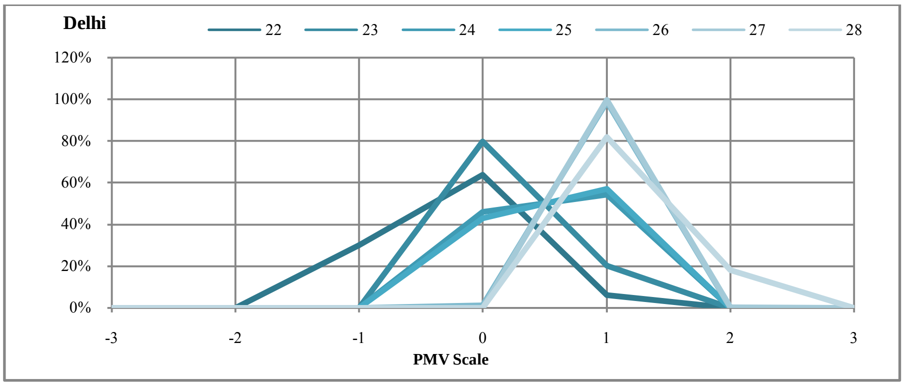

Figure 7 *Comfort conditions for Delhi at given setpoint temperatures*

Table 7EPIat particular Setpoint temperature and COP value for Delhi

SETPOINT/COP	2	3	4	5
22˚C	**90**	60	45	36
23˚C	84	56	42	34
24˚C	78	52	39	31
25˚C	73	48	36	29
26˚C	67	45	34	27
27˚C	61	41	31	25
28˚C	56	37	28	**22**

Comparison:

At the very first observation, comparing the case of Bangalore (Table 5) to Ahmedabad (Table 1), the highest annual cooling energy consumption at setpoint 22˚C for COP 2 is 103 units for Ahmedabad where as it is as low as 84 units for the case of Bangalore. By changing the COP value from 2 to 3, the reduction in cooling energy consumption is 29 units for Bangalore whereas the reduction is more significant (35 units) in case of Ahmedabad. For COP 3, there is a reduction of on an average 4 units per degree setpoint temperature in Bangalore. In case of Ahmedabad the difference is of 2 units. Bangalore and Guwahati (Table 6) shows a very similar consumption pattern for all temperatures and COP values with a difference of 3 to 4 units, Bangalore being the lowest. Likewise, Chennai and Ahmedabad shows similar trend of consumption, Ahmedabad being the highest of all the cities (Table 4).

CONCLUSION

The most important observation of this study is that, low cooling setpoint temperature does not contribute significantly in lowering the cooling energy consumption at higher COP value of the PTAC cooling system. This is, however, true only for systems with average or low efficiency. The study proves through quantification the importance of using appropriate COP for achieving cooling energy savings while maintaining thermal comfort.

The outdoor environment also plays an important role in determining the trade-offs between comfort and cooling energy consumption. For instance, it was observed that Ahmedabad and Chennai had the highest cooling energy consumption of 103 and 97 units at COP of 2 and setpoint 22˚C, whereas Bangalore, Guwahati and Delhi show almost 8 to 10 units less cooling energy consumption for the same cooling setpoint and COP values.

Another important observation for each city is that the comfort levels at 24˚C and 25˚C are more or less the same (more than 50% of the occupants feel neutral on PMV scale). 24˚C setpoint consumes almost 6 % higher cooling energy annually than 25˚C (Table 3) so one can make a decision of maintaining one degree higher and contribute in saving cooling energy consumption.

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Examination of Indoor Thermal Environment and Energy Performance by Active Air-conditioning Control System utilizing Adjustment Behavior of Occupants

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ABSTRACT

This study examined an active air-conditioning control system with SaaS-type BEMS (Software as a Service-type Building Energy Management System). The SaaS-type BEMS controls building facilities through the Internet and can be easily introduced to existing small or medium-size buildings. The objective of Active Air-conditioning Control(AAcC) is active energy saving by controlling the operation of indoor equipment and features a mechanism to prevent room environment degradation by utilizing people's action of turning on/off of the air conditioner. This paper presents the room environment and energy saving effect of the system in summer if introduced to the office room of a middle-size building.

INTRODUCTION

Reduction of greenhouse gas emissions and increasing energy saving have become major societal issues. Measures to combat the former and optimize the latter have become especially urgent in Japan. Energy saving by whole societies, regardless of size, has been promoted through energy-saving actions on various types of facilities and buildings. However, energy management systems have been rather slowly introduced to small and medium-sized office buildings. As an air-conditioning system satisfying the thermal comfort request of occupants while achieving energy saving, a personal air-conditioning method is expected. However, this method is mainly applied to a new building, and its application is limited.

The present study examines a novel AAcC system installed on a SaaS-type BEMS. The system is easily introduced to small and medium-sized buildings, since a virtual BEMS can be configured to the building's physical equipment settings.

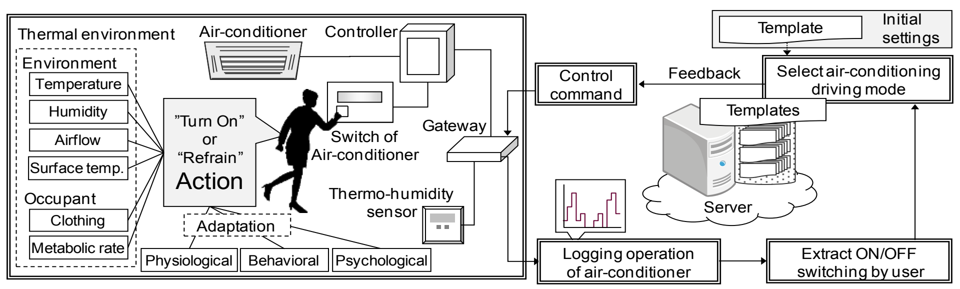


Figure 1. Active energy-saving air-conditioning control system.

Energy saving is achieved by active control of the indoor air-conditioning unit. The control system also reduces deterioration of the room conditioning by sensing the occupants' on/off switching of the air conditioning.Ultimately, the system should satisfy the thermal comfort requests of the occupants by feedback of their adjustment behavior, rather than by collecting the details of the occupants' attributes, thermal and comfort sensations, and psychological conditions.

In this paper, our proposed energy-saving system was evaluated in the office space of a medium sized building during the summer season.

OVERVIEW OF ACTIVE ENERGY-SAVING CONTROL FOR AIR-CONDITIONING SYSTEM

Figure 1 shows an operation diagram of the AAcC system. The system controls the air conditioning based on templates that describe ON/OFF commands for an air conditioner. It starts the control with an initial template. Then an appropriate template is selected in accordance with the template selection standard and is loaded to execute air conditioning control according to the ON/OFF commands described in the selected template. The template selection standard of this system is based on the number of switching-on/off actions of people in the room.

THE EXPERIMENT METHOD OF THE OFFICE IN SUMMER

A verification test was conducted in the period from July 8, 2013 to September 30, 2013 at a building N in Tokyo. Table 1 gives an overview of the building. There were nine indoor air conditioning units in the office room, one in each of three neighboring rooms, and one in a meeting room. The outdoor unit (1) covers all of these thirteen indoor units. Each air conditioning unit can be started and stopped independently.

Figure 2 shows the layout of the office room and the location of the indoor units, air thermo-humidity sensors, and globe thermo sensors. Since there was a building on the south-west side of the office, almost no direct sunlight entered the office except in some areas. Some windows of the office room had a window shade. A photograph and thermographic image of the room are given in Figure 3. The temperature and humidity were measured at five locations with wireless sensors and thermo-humidity sensors with a memory function, and the radiation temperature was measured at the room center with a globe thermometer. The number of manual switching operations of the indoor units and the total electricity consumption of the outdoor unit were also measured periodically by the SaaS type BEMS. Measurements were taken at intervals of 5 minutes.

Table 1 Summary of the building

Location	Tokyo, JAPAN			
Use	Office Building			
Dimension	10 Floors, Underground 1F			
Total floor space	8,664.09 m^2			
Ceil Height	2.5m (Std. Floor)			
Occupied Area	486.7m^2			
Office Area	321.2 m^2			
Meeting Room Area	165.5 m^2			
Type of Air-Conditioning System	Multiple Air-Conditioning System			
Air-Conditioning Unit Spec. (Cooling)				
Area	**Unit**	**Cooling Capacity**	**Power Consumption**	**COP**
Office	Outdoor	90.0kW	27.67kW	3.25
	Indoor	-	0.80kW	-
Meeting	Outdoor	54.0kW	16.40kW	3.41
	Indoor	-	0.50kW	-

Table 2 ON/OFF control template for Air-conditioning

	Driving Mode	Reduction Rate	Indoor Unit Series	0	5	10	15	20	25	30	35	40	45	50	55
to reduction→	1	67%	A	OFF		ON	OFF		ON	OFF		ON	OFF		ON
			B	ON	OFF		ON	OFF		ON	OFF		ON	OFF	
	2	58%	A	OFF	ON	OFF		ON	OFF	ON	OFF		ON	OFF	ON
			B	ON	OFF		ON	OFF	ON	OFF		ON	OFF	ON	OFF
	3	50%	A	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON
			B	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
	4	33%	A	ON		OFF		ON			OFF		ON		
			B	OFF		ON			OFF		ON			OFF	
←to increase	5	33%	A	ON	OFF	ON		OFF	ON		OFF	ON		OFF	ON
			B	ON		OFF	ON		OFF	ON		OFF	ON		OFF
	6	25%	A	ON		OFF	ON			OFF	ON			OFF	ON
			B	OFF	ON			OFF	ON			OFF	ON		
	7	17%	A	ON			OFF	ON				OFF	ON		
			B	OFF	ON				OFF	ON				OFF	ON

Operation interval of the indoor unit: columns 0–55.

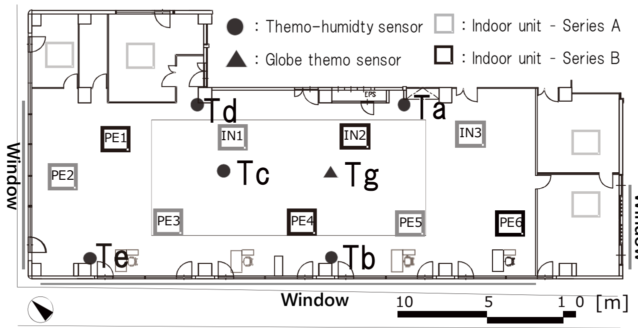


Figure 2. Position of indoor air-cooling unit and measurement points

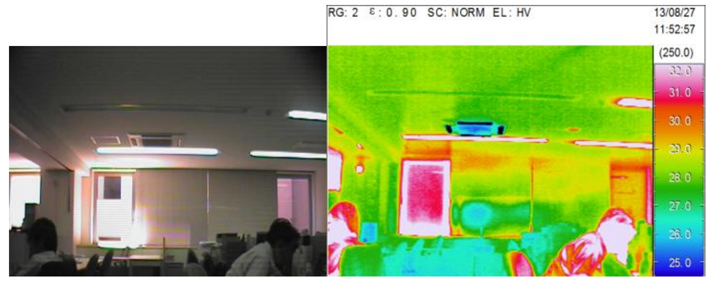


Figure 3. Infrared thermography image of South side

Next the air conditioning control method employed for the present experiments is explained. As shown in Figure 2, the indoor units were alternately grouped to Series A and Series B and each series was controlled separately. Simultaneous operation of Series A and Series B makes 100% operation and the operation of Series A only reduces the operation load by about 50%. Seven driving modes of different operation reduction rates were defined for intermittent operations of each series as shown in Table 2. The AAcC method switches the driving mode to a more energy-saving type when people in the room perform less temperature-adjustment actions and to a less energy-saving type when they perform more temperature-adjustment actions. Therefore, the driving mode changes according to the number of manual switching-on/off actions which are considered as the temperature-adjustment actions of the people in the room.

The present verification experiments used Mode 4 on the first day (July 8) to start the air conditioning of the office. On the next day, the previous day's status information of each indoor unit is analyzed at 0 o'clock to calculate the total number of manual switching-on/off actions of the people. When this total number is in the range from 0 to 74 per day the system changes the mode by one step to the energy-saving side, when in the range from 75 to 150 per day the system maintains the mode, and when it is more than 150 per day the system changes the mode by one step to the less energy-saving side. If no AAcC is made on the previous day, the mode selected on the last day that the control was made is maintained. Therefore, if the previous day is a holiday, the control is conducted in accordance with the control results of the last active air-conditioning controlled day.

THERMAL ENVIRONMENT AND THE RESULTS OF MODE CHANGES OF AIR-CONDITIONING OPERATION

Figure 4 shows the changes of the thermal environment of the office from August 19 to 21 in summer at an outdoor temperature over 30°C. August 19 was the first work day after the summer vacation. The indoor air temperature (hereafter referred to as room temperature) was controlled to be about 28°C with a variation of 2-3°C depending on measurement points, which caused the non-uniform thermal environment. The temperature change by switching on/off the air conditioning was 1-1.5°C on August 20 and 21. In the mode used on August 19, the air conditioning operations were stopped for a prolonged period and hence the temperature variation was expected to be large. However, the actual temperature variation was smaller at each measurement point than the variation on the next day having less energy reduction. This was because the people's temperature adjustment actions corrected the temperature variation. Figure 5 shows the mode change in the AAcC, indoor temperature (average over work hours), and outdoor temperature (in Tokyo) in July. There is no data for holidays, July 26, and August 7 and 27 when the AAcC was not performed. Figure 6 shows the total number of manual switching-on/off actions in a day in the area, except the meeting room, covered by the outdoor unit (1).

The room temperature was maintained at 26-28°C irrespective of the outdoor temperature. On the first day (July 8) of the AAcC, the number of switching-on actions of the people in the room was small, less than 75 per day. Therefore, the air conditioning mode was changed to mode 3 (reduction rate 50%) to save more energy. However, on July 11, the switching-on actions became more frequent and the mode returned to mode 4. On July 16 and 17, the mode was switched successively to mode 1 due to the small number of switching-on actions, and mode 1 was maintained on and after July 18. Since the number of switching-on actions was 151 or more per day on July 31, the mode was changed the next day to mode 2 to reduce the energy saving. The air conditioning mode was selected to be 3 or 4 in early July because of the record-breaking hot weather, but the outdoor temperature decreased in the middle of July and more energy-saving modes were used for the air-conditioning control.

In other words, the AAcC could follow the relatively slow change of the thermal environment caused by the influence from the outside environment.

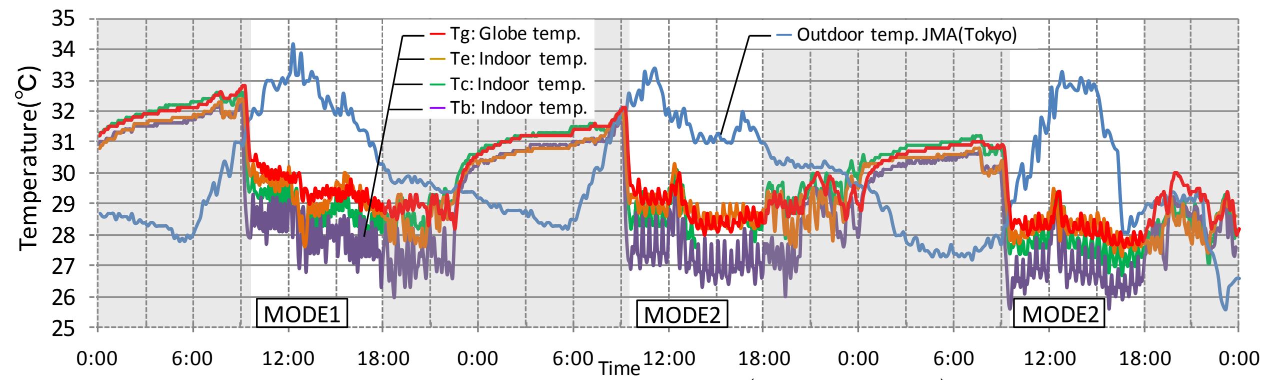
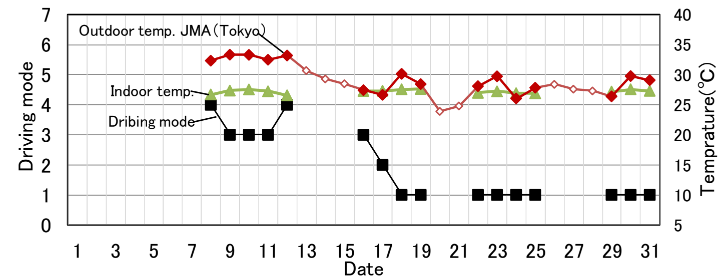


Figure 4. Thermal environment of office（19-21.Aug.2013）



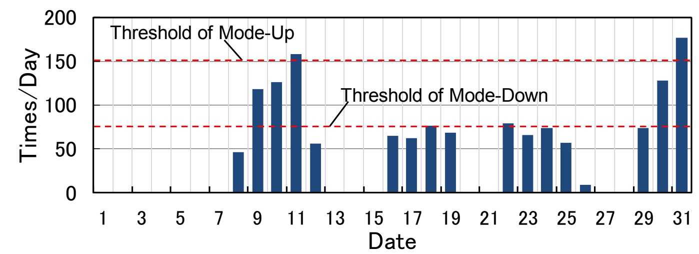


Figure 5. Thermal enviroment and Driving mode of office (Jul.2013)

Figure 6. ON/OFF action count (Jul.2013)

DIFFERENCE IN TEMPERATURE ADJUSTMENT ACTIONS IN DIFFERENT PLACES IN OFFICE

Figure 7 shows the total number of manual switching-on/off actions for each indoor unit over July 8 to 31 and August 1 to 31. The switching-on/off actions were more frequent on the perimeter side than on the interior side, and more on the east side than on the west side. This could be because the units on the perimeter side and those on the interior side were operated intermittently in the same mode and hence those on the perimeter side that could be easily affected by the outdoor environment were switched on/off more frequently. Also the number of switching-on/off actions was not the same for the indoor units on the perimeter side or for the units on the interior side. This could be because of the non-uniform thermal environment, difference in the each person's position, attribution, thermal sensation, comfort, and psychological conditions.

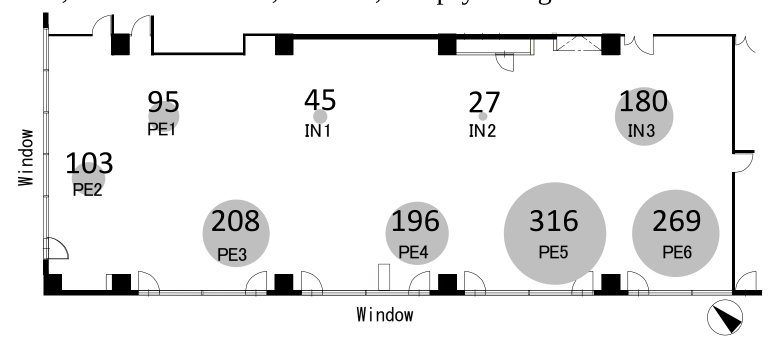


Figure 7. Count of switch every indoor unit (Jul.2013)

RESULTS OF INDOOR UNIT OPERATION SUPPRESSION AND ENERGY CONSUMPTION REDUCTION

Table 3 shows the expected reduction rate[Note1)] of the intermittent operations and the actual reduction rate calculated from the actual air conditioning operation hours.

The reduction rate difference [%]= Expected reduction rate [%] – actual reduction rate [%] in each mode

Table 3 Reduction rate of A/C indoor unit of office area

Month	Days of Auto Control (day)	Estimated Rate (%)	Usage of Room (h)	Usage of A/C (h)	Run. Rate of A/C (%)	Reduction Rate of A/C (%)	Outdoor Temp. JMA(Tokyo) (°C)
Jul.	11	64.4	82.5	38.4	46.6	53.4	27.3
Aug.	15	60.5	112.5	57.1	50.8	49.2	29.2
Sep.	19	65.8	142.5	60.0	42.1	57.9	25.2

The air conditioning driving mode changed every day according to the feedback from the people's temperature adjustment behaviors. The mode change in July, August and September when the AAcC was conducted was recorded. The data in the first week of July were omitted since this was the period for the AAcC to meet the condition As a result of the measurement, the expected reduction rate in July was 66.4% and the actual reduction rate was 53.4%, smaller than the expected rate due to the people's temperature adjustment. The expected reduction rate and the actual reduction rate were both smaller in August than in July but larger in September. This could be because the outdoor temperature in August was high and that in September was lower than in July and August. Since the difference between the expected and actual reduction rates was 7.9-11.3%, one can see that the people's temperature adjustment actions changed the mode by 1 step and the office was controlled in this mode range. To reduce this difference, the threshold (total number of manual switching-on/off actions) of the mode switching to higher energy consumption should be set to a small value. However, this may cause excessive air conditioning with higher energy consumption. It is therefore important to select an appropriate threshold.

Table 4 shows the comparison with the power consumption in 2010 when the air conditioners were kept switched on at 28°C. The energy consumption of each air conditioner was not measured in 2010 but the total consumed energy and the working hours of the indoor units were measured. The power consumption of the indoor and outdoor units was estimated from these measurements[Note2)]. The total consumption energy of the air conditioning estimated from each of the units was 11,945kwh, about 4% deviated from the actual measurement value 12,402kwh, indicating that the estimation was effective. It is concluded from this result that the energy consumption in the office room in 2013 was reduced by 46% in 2010 by the AAcC. The outdoor temperature was lower by 0.7°C in July, 0.4°C in August, and 0.1°C in September than in the same months in 2010. However, the influence of this difference is small since the change in the energy consumption of the outdoor unit due to the outdoor temperature change is 180.1kwh/month-°C. The office was used for 58 days in July, August and September both in 2010 and 2013. Although the number of people decreased by 10%, the use condition was almost the same in both years.

Table 4 Power reduction result (Jul.-Sep. 2013 vs Jul.-Sep. 2010)

Division		Control method	Jul.-Sep. 2013 Active air-conditioning control	Jul.-Sep. 2010 Temperature-constant control (28°C)		Reduction rate
			Measured	Measured	Estimated*	
Outdoor unit(1) (office area)						
	Indoor unit working time (h)		3420	6374	-	
	Detail	Office area (9unit) (h)	2788	5631		50%
		Other (4unit) (h)	632	743		15%
	Indoor unit (kWh)		256		476	
	Outdoor unit (kWh)		4118		7676	
	Power consumption (kWh)		4374		8152	46%
Outdoor unit(2) (Meeting room area)						
	Indoor unit working time (h)		1476	3866	-	62%
	Power consumption (kWh)		1448		3793	62%
Total						
	Air-conditioning electric power consumption (kWh)		5822	12402	11945	53%

* The estimated values of each electric consumption is estimated from indoor unit working time of 2010 based on air-conditioning electric consumption per indoor unit working time of 2013.

The above facts indicate that the major causes for the energy consumption reduction were the suppression of the air conditioning operations during the office hours as shown in Table 3, and prevention of forgetting to stop the air conditioners after office hours or unnecessary operation of them by the automatic termination of the air conditioners after office hours, which had been controlled manually.

CONCLUSION

In this study, an active air-conditioning control (AAcC) system was introduced to an office room where there were multiple indoor air-conditioning units and analyzed based on verification experiments conducted in summer with the focus on the thermal environment and the temperature adjustment actions of people in the room. By incorporating occupants' switching on/off action into the system, this control method enables the automatic control of air-conditioning along with the thermal comfort request of occupants. Major results are as follows.

1) The AAcC was conducted at a preset temperature of 26°C in an office room with multiple indoor units, which were alternately grouped into two. After the air conditioning mode is stabilized, the mean room temperature was maintained at 26-28°C irrespective of the outdoor temperature. The temperature variation at the sensor positions due to the start-stop operations of the indoor units was 1-1.5°C and the room temperature variation across the office room was about 2-3°C.
2) The air conditioning operation reduction rate for the office room was 53.4% in July, 49.2% in August, and 57.9% in September.
3) The results indicated that the AAcC of the office area in 2013 reduced the energy consumption by 46% from the consumption in 2010. The major causes for the large reduction are the suppression of the operation of the air conditioners during the office hours and the prevention of forgetting to stop the air conditioners after office hours.
4) The number of manual switching-on/off actions varied from place to place in the room and differed between the perimeter side and the interior side. It was therefore found that people's preference on the thermal environment could be deduced from their air conditioner adjustment actions.
5) In the air-conditioning control according to the number of people's switching-on/off actions, the AAcC could follow a change in the thermal environment caused by the influence of the outdoor temperature.

The above results showed that the AAcC based on the number of people's air conditioner adjustment actions realized air-conditioning control appropriate to the thermal environment of an office room with multiple air conditioners.Since the number of switching-on/off actions was counted every day, the system could follow only a slow thermal environmental change over two or more days. It was also clarified that holidays needed to be taken into consideration. Also, each indoor unit should be controlled separately to compensate for the variation of the thermal environment across the room.

The change-following performance should be improved by using a shorter period of the feedback from the number of manual switching-on/off actions in people's temperature adjustment behavior or by using the weather forecast data, and a system of applying the AAcC to each of the indoor units separately.

Note 1) The expected reduction rate was calculated from expected working hours of the air conditioners in office hours (7.5h). The expected working hours of the air conditioners were given by summing up the expected working hours calculated from every day's air conditioning modes.

Note 2) The power consumption per operating hour of indoor units, that of outdoor units, and that of air conditioners is calculated from the measurement results in 2013 (July to September) and from the total working hours of indoor units in 2010. Since the specifications of the indoor and outdoor units are different in the office area and in the meeting room area, the power consumption was calculated separately for each of the areas.

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THERMAL COMFORT IN HOUSING OF THE METROPOLITAN AREA OF THE VALLEY OF MEXICO

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ABSTRACT

This research is based on the principles of adaptive focus. In this document, the results of the field research on thermal comfort regarding housing produced in series are presented. The survey was conducted in the municipalities of the Metropolitan Area of the Valley of Mexico that have presented the most urban growth in the last 10 years. Measurement times were determined according to bioclimatic analysis: cold, warm and transition. The environmental variables, such as dry bulb temperature, wet bulb temperature, black globe temperature, relative humidity and wind speed in the living room of the houses, were measured while, simultaneously, 426 surveys about thermal sensation were conducted to the inhabitants. The questionnaire was performed according to ISO 10551 and ASHRAE 55 Regulations. The annual neutral temperature in naturally ventilated houses in the Metropolitan Area of the Valley of Mexico is 21.3ºC and extensive thermal comfort limits are 16.0ºC and 26.7ºC. The Mexico's Energy Efficiency Standard in residential buildings, NOM 020 ENER-2011, suggests that the ideal temperature for interiors is 23°C, which is inconsistent with the neutral temperature resulting from the investigation; therefore, considering it favors the use of artificial devices for air conditioning and the energetic cost of housing.

INTRODUCTION

The purpose of the neutral temperature and ranges of thermal comfort in the housing of the Metropolitan Area of the Valley of Mexico, allows the development of tools and information that is useful for the planning and designing of houses which promote the thermal comfort wellbeing of residents. The perception of thermal comfort is important for carrying out activities without compromising the physical and mental performance of the subjects, however, if the thermal environment does not provide the right conditions, the subjects can take action to adapt or reduce the length of their stay in that space (Bojorquez Morales, 2010).

The ASHRAE 55-2004 Regulation incorporates the method for determining acceptable thermal conditions in naturally ventilated environments. This method was based on work done by de Dear and Brager (1998), in which several climatic zones were analyzed, each in different countries and buildings. However, data from countries in Latin America and Mexico are not included. In order to establish standards for thermal comfort, in the last years there have been investigations on thermal comfort in countries that were not included in this rule; Japan (Bahadur, 2013), China (Wang, et al., 2010), and several cities with warm weather in Mexico (Gomez Azpeitia, et al., 2009).

This investigation is based on the focus of adaptation, since it allows to evaluate, both, the subjects' perceived thermal sensation in a natural environment and the psychophysiological reactions generated to feel comfort.

The climate analysis determined the study periods: cold (December-January); warm (May); and transition (October-November, March). The field work consisted in conducting surveys, regarding thermal perception, to residents of municipalities with the highest urban expansion in 10 years. During the three periods, 377 observations were obtained.

METHOD

The investigation was divided in three stages: 1) Site Analysis, in which the urban growth in the Metropolitan Area of the Valley of Mexico (MAVM) was diagnosed to determine areas of study, and a description of the climate to show environmental conditions was made; 2) Correlational Study, in which the measurement periods, variables and instruments were defined; and the questionnaire and the sample was designed; 3) Data Analysis, which was by an unconventional method of regressional statistics by layers.

1. Site Analysis

The selected municipalities are the top ten municipalities with the highest population growth in the last ten years. As shown in Table 1, the number of houses built is greater than 5,000. The condition in order to be among the selected was that the average annual temperature could not present variations greater than 1°C. The field study was conducted in houses produced in series of the municipalities of: Tecamac, Nicolás Romero, Cuautitlan Izcalli, Tultitlan and Huehuetoca.

Table 1. Location Description

#	LOCALITIES	# HOUSING	LATITUDE (N)	LONGITUDE (w)	ALTITUDE (m.a.s.l.)	LOW TEMP.	AVERAGE TEMP.	HIGH TEMP.
1	Tecámac	132,275	19°39'24"	99°01'02"	2,340	6.9	15.6	24.4
2	Nicolás Romero	15,012	19°34'52"	99°16'42"	2,360	6.9	15	23.1
3	Cuautitlán Izcalli	11,964	19°42'16"	99°13'09"	2,365	7	15.6	24.1
4	Huehuetoca	7,653	19°41'03"	99°07'36"	2,245	6.1	14.9	23.5
5	Tultitlan	7,305	19°50'55"	99°12'45"	2,258	6.1	14.8	23.5

Table 1 shows the location of the municipalities, minimum temperatures, average and annual maximums, as well as the number of built houses which were produced in series.

2. Correlational Study

The questionnaire on thermal sensation was designed according to the ISO 10551 Regulation, using the 7-point scale (Table 2); and proposed in the study "Thermal comfort and Energy Savings in Affordable Housing in Mexico" (Azpeitia Gómez, et al., 2009), based on the previous rules.

Table 2. Thermal sensation scale by ISO 10551

#	VALUE	COMFORT VOTE
7	3	Hot
6	2	Warm
5	1	Slightly warm
4	0	Neutral
3	-1	Slightly cool
2	-2	Cool
1	-3	Cold

The survey was conducted on healthy subjects from 15 to 60 years of age, with average levels of clothing from 0.30clo to 1.5clo. The subjects were grouped into three levels of physical activity: passive or resting, from 0 to 75W/m^2, moderate with 76W/m^2 to 180W/m^2 and severe, greater than 185W/m^2; simultaneously the surveys were measured by the following variables: dry bulb temperature (TBS), wet bulb temperature (TBH), black global temperature (TGN), relative humidity (RH) and wind speed (VV); the measurements were performed with a heat stress monitor, which according to the ISO 7726 (1998) Regulation the information obtained is classified in Group I.

To determine the study periods, de Dear's and Brager's (1998) neutral temperature equation ± 2.5K was applied to normal weather of the before mentioned municipalities. The periods are shown in Table 3. The study sample was determined by the amount of affordable housing built and the total population of people of the ages between 12 and 60 years of the MAVM. It was decided, based on statistical data, that the sample should include at least 120 people per measurement period. The selection of subjects who were surveyed was random within housing developments, and deterministic, since the subjects were the ones who chose to part take or not part take in research.

Table 3. Measuring periods

ZONE	PERIODS	MONTHS	# OF SAMPLE
MAVM*	Transition	October November March	152
	Cold	December January	135
	Warm	May June	139

*Selected locations of the Metropolitan Area of the Valley of Mexico

For the conducting of the surveys, students of the Universidad Autónoma Metropolitana were trained and trial surveys were conducted to improve the application method and become familiar with the measuring equipment. Fieldwork was conducted from 09:00 hrs. to 19:00 hrs. and the data collected on site were captured using an Excel database to facilitate statistical analysis.

3. Data Analysis

The statistical method of analysis, was a nonconventional method of linear regression by layers, developed by Gómez-Azpeitia et al. (2007), was based on Nicol's (1993) proposal. The main difference with the conventional method is that prior to obtaining the regression, the sample is grouped by levels of perceived thermal sensation. After obtaining the average values of temperature (TMean) and standard deviation of the responses for each level of perceived thermal sensation, distribution ranges are establishes for each response category from the value of the corresponding TMean and adding or subtracting 1σ, representing 68% of the population whom expressed the same thermal sensation; the adding procedure is repeated, this time by adding or subtracting 2σ, representing 95% of the population.

Finally, the linear regression is done with the series of values of TMean, ±1σ and ±2σ of each thermal sensation. The intersection of each of the regression lines with the ordinate four (corresponding to the thermal comfort sensation) determines the value of the neutral temperature, as well as the limits of the comfort zone. In this method, what determines the validity of the regression, is the determining coefficient resulting of the straight line (R^2); this value ranges from 0 to 1, while it is closer to one, the value obtained has more representation on the sample, in other words, greater validity.

Figure 1 shows the graphs obtained from the data analysis collected from the field work done under the above mentioned method; TMean regression lines are observed, ±1σ and ±2σ, like the intersection of these, with the value of 4 for the ordinate *y*, which gives origin to the neutral values of temperature and thermal comfort range.

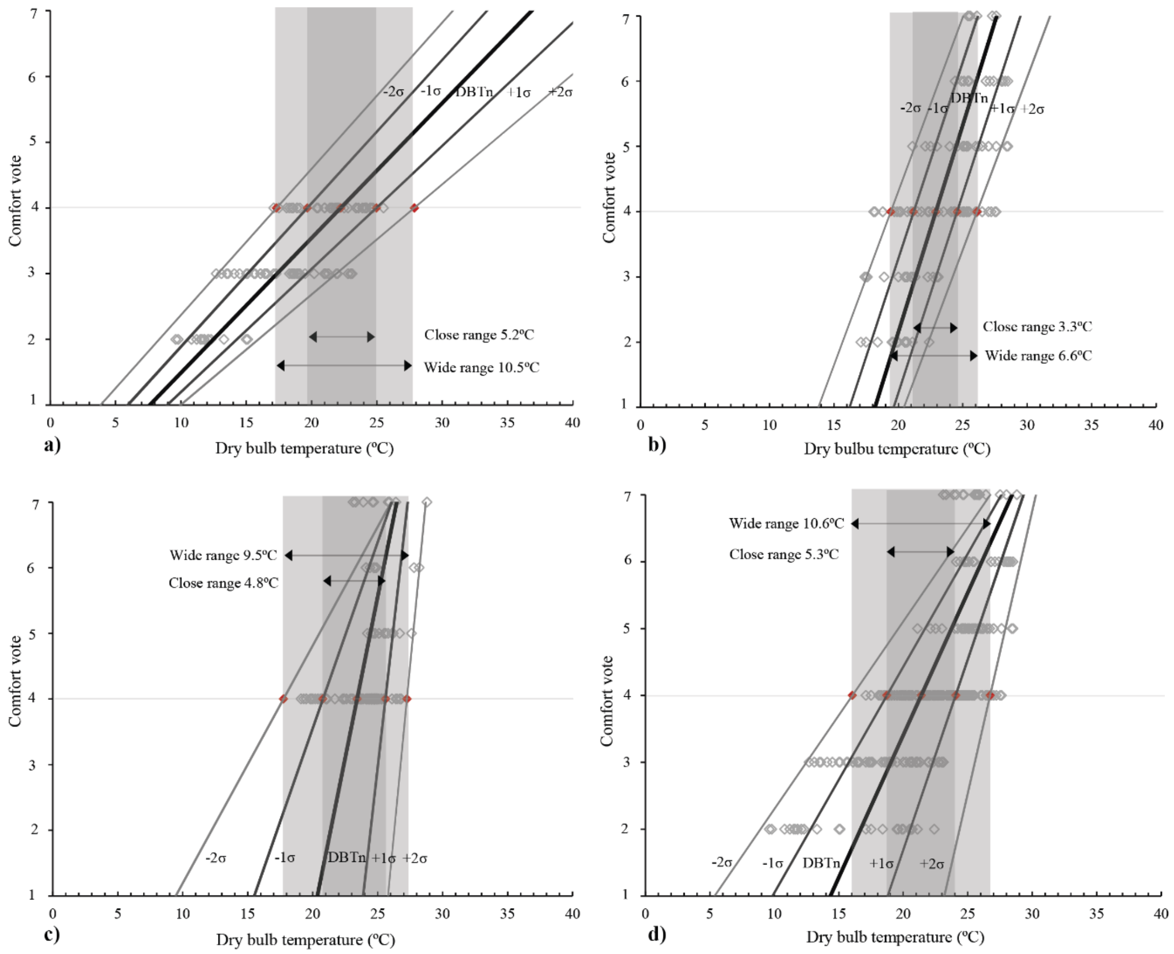

Figure 1. Determination of Tn and the comfort ranges by non-conventional method of statistical regression by layers in Metropolitan Area of Mexico. **(a)** Cold period **(b)** Transition period **(c)** Warm period **(d)** Annual

Figure 1a shows that the regression lines of -2σ y -1σ visually are parallel to the average line of regression, however, they are slightly convergent as the sensations increased from 2 to 4, which represents that the thermal perception of temperatures less than 22.2°C is similar in all the sensations. Lines +2σ and +1σ have the same behavior but with steeper slopes, indicating that when the temperature is above 22.2°C the capability of adaptation is reduced during cold sensations. Figure 1b shows some observations outside the limits of comfort sensations 6 and 7 to the limit +2σ, which indicates that most subjects have a preference for temperatures below 27.2ºC. The regression lines ±1σ and ±2σ are divergent in regards to the mean regression line as the cold sensation increases, which indicates that subjects are better able to adapt to these conditions in the warm period.

In Figure 1c, the regression lines -2σ y -1σ are visually parallel to the average regression line, however, are slightly convergent as the sensation increases from 6 to 7, the opposite occurs with the regression lines +2σ and +1σ which are slightly convergent to the sensations of cold; indicating that when temperatures are below 22.9°C the subjects show less adaptability to the sensations of heat, and the opposite occurs when they are higher. Figure 1d shows that the regression lines of ±2σ and ±1σ are divergent to the regression line Tn average as the thermal sensation of cold increases, which indicates that each year there is more capability of adaptation to these conditions; however sensations 3 and 2 show greater scatter in the data, which is possibly due to clothing levels and metabolic activity of the subjects; the levels of activity in these sensations were: 40% while resting, 55% in moderate work and 5% during intensive work; while 80% of the subjects were dressed between normal and snug (from 0.60 to 1.0clo).

RESULTS

The resulting values of the above analysis are presented in Table4; the neutral temperature, reduced and extensive limits of the thermal comfort zone and degrees of openness each study period has are shown. It is observed that the lowest value of Tn is the transition period, this is because in these months the weather has greater fluctuation, making it difficult for subjects to adapt to the thermal conditions; the highest value is observed in the cold period, which means that subjects have greater adaptation to thermal conditions that occurred in this period, which is consistent with the mild climate of the MAVM. The neutral temperatures resulting from the analysis in each period have a difference = or <5%; however, as shown in Table 4, the lowest value of Tn is given in the annual evaluation, since this one takes into account all the observations.

Table 4. Comfort temperatures and ranges determined in the field study

ZONE	PERIOD	Tn	COMFORT CLOSE RANGE Lower Limit	COMFORT CLOSE RANGE Upper Limit	COMFORT CLOSE RANGE Rank	COMFORT WIDE RANGE Lower Limit	COMFORT WIDE RANGE Upper Limit	COMFORT WIDE RANGE Rank
MAVM*	Transition	22.9	21.1	24.5	3.4	19.4	26.1	6.7
	Cold	22.2	19.6	24.9	5.3	17.3	27.8	10.5
	Warm	23.4	20.7	25.6	4.9	17.7	27.2	9.5
	ANNUAL	**21.3**	**18.7**	**24.0**	**5.3**	**16.0**	**26.7**	**10.7**

* Selected locations of the Metropolitan Area of the Valley of Mexico

Table5 shows the comparative analysis of neutral temperatures obtained with the equations proposed by different authors; it is apparent that in all the periods the neutral temperature resulting from this research is more the others, therefore, suggests an adjustment to the models of assessment of thermal comfort for the mild climate of the MAVM. However, the Tn results of de Dear's and Brager's (1998) equation, has a smaller difference of 1°C with the results obtained, which is an indicator for validating data through the application of ASHRAE Standard55- 2004.

Table 5. Comparative chart of comfort temperatures calculated by different authors

ZONE	PERIODS	To*	Neutral Temperature (Tn) Humpreys	Neutral Temperature (Tn) Auliciems	Neutral Temperature (Tn) Griffiths	Neutral Temperature (Tn) de Dear & Brager	Neutral Temperature (Tn) Field Study
MAVM	Transition	14.3	19.7	22.1	19.8	22.3	**22.9**
	Cold	11.6	18.2	21.2	18.3	21.4	**22.2**
	Warm	17.5	21.4	23.0	21.5	23.2	**23.4**
	ANUAL	15.1	20.1	22.3	20.2	22.5	**21.3**

*To: monthly average outdoor temperature

Finally the method was applied to determine the acceptable thermal conditions in naturally ventilated spaces (ASHRAE Standard55- 2004). Figure2 shows the analysis through period of acceptable operating temperatures. It is observed that the thermal conditions of the houses fall in the range of 90% acceptability of this standard.

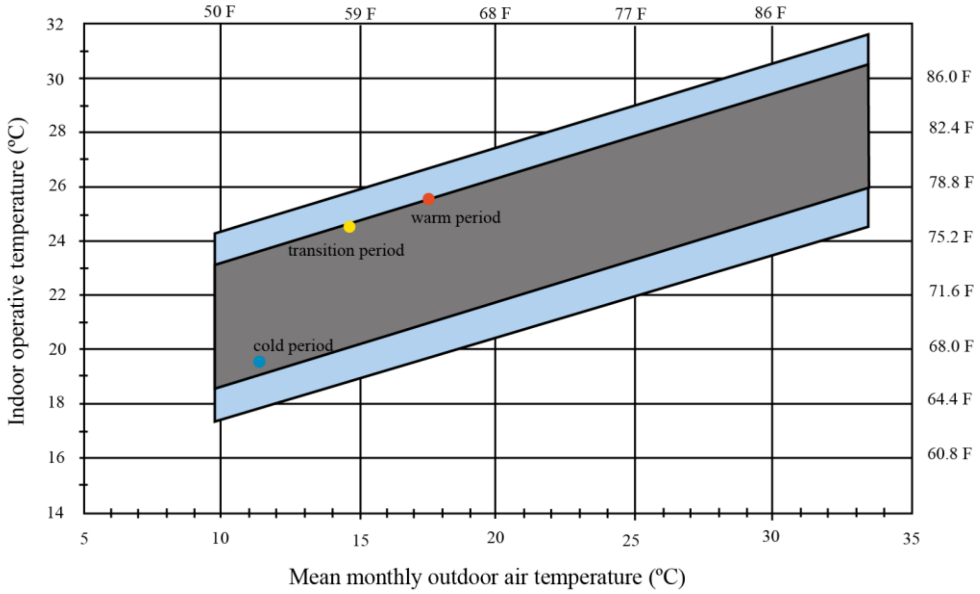

Figure 2. Acceptable operative temperature ranges by study period in naturally ventilated housing in MAVM (ASHRAE Standard55, 2004).

CONCLUSIONS

The ability to adapt to the thermal environment of houses built in mass production in the Metropolitan Area of the Valley of Mexico, is now higher; considering that 94% of the subjects said that the environment of their home was acceptable; nevertheless, only 48% said they felt comfort, possibly due to physical factors that were not evaluated in this investigation.

The annual neutral temperature in housing produced in series with natural ventilation in the Metropolitan Area of the Valley of Mexico is 21.3ºC, with a narrow range of ± 2.7ºC thermal comfort, for that reason it is suggested to make the appropriate amendments to Mexico's Energy Efficiency Standard, NOM 020-ENER-2011, which suggests an internal temperature of 23°C, hence, favors the use of active devices to acclimatize spaces. .

Finally, the study validates the use of the adaptive method of ASRAE 55- 2004 Standard to determine the thermal comfort conditions of the houses in the Metropolitan Area of the Valley of Mexico.

ACKNOWLEDGMENTS

This research was supported by the PROMEP project, "Lineamientos para el confort y desempeño energético de la vivienda urbana" ("Guidelines for the comfort and energy performance of urban housing"). I would like to extend my gratitude to the Universidad Autonoma Metropolitana, to all those who participated in the study and made possible its progress, to the people who conducted the surveys and partook in the fieldwork and to my partner, April Rueda, for her important collaboration and support in this investigation.

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Session 5D : Tools and methods/ framework

PLEA2014: Day 2, Wednesday, December 17
11:30 - 13:10, Trust - Knowledge Consortium of Gujarat

Empirical and software verification of a simplified predictive model of luminous efficiency of light-pipes

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ABSTRACT

This article presents the verification of a mathematical model for predicting the luminous efficiency of light-pipes, based on the principle of unit hemisphere and solid angles. For this, light-pipes were simulated in the software photopia and essayed under real sky conditions. The adopted method in this research is theoretical deductive, developing a luminous efficiency predictive model of light-pipes and its complementation by the lumens methods. In order to verify the results, an empirical inductive method was applied, considering physical models under real sky conditions. In addition to the empirical results, simulations were carried out in raytracing software Photopia. The first method calculates the value of the relationship (LPE) between the availability of light in the central point in the output section of the light-pipe and that in the horizontal plane of its entrance. The high correlation found between results from the measured data and results from the proposed luminous efficiency predictive model of light-pipes (LEPMLP) with the results obtained from the software Photopia, in terms of estimated values of light-pipes efficiency (LPE), showed that it is a reliable tool and is easily applicable for dimensioning this kind of system for taking advantage of daylighting in everyday architectural and building design practice, allowing to deliver daylight to rooms without direct contact with the external environment.

INTRODUCTION

The global scenario has been changing with the exigencies of the environment resources, which were used by past generations inconsequently. Currently, the concern for the planet and future generations puts emphasis on the use and development of efficient products that consume or use clean or renewable energy. In this context, light -pipe systems are developed to conduct the daylight to internal environments far from the envelope, as, for example, rooms without direct contact with the external environment or in undergrounds.

Consiering the advances in researches, new technological innovations have been developed to bring daylight to indoor environments. A variety of devices aimed at lighting were designed and researched to improve the quality of daylighting to increase user acceptance and provide tools for designers to specify and size these systems.

Kocifaj et al. (2008) observe that beginning research on products of light had interest in the innovative system, seeking to eliminate the deficits and gaps offered by conventional systems openings. In the beginning, installed systems have been researched and prototypes as a "black box" comparing the performance of the system as a whole with other systems. Within this group are works such as: Al-Marwaee & Carter (2006), Oaklley et al. (2000). In a second step the interest of the academic community becomes more specifically to the driver turning his scientific interests to the efficiency of those seeking to unravel the behavior of light to be conducted this phenomenon and propose predictive models resulting in the prediction of the efficiency of light transmission along the conductor and several theoretical predictive mathematical models and semi- empíricos.Esse in the case of papers presented by Swift & Smith (1995), Swift et al.(2008) and Luz et al (2010). Finally, recently, in the third stage of the research for the products of light, the interest is focused on the transport of light from the diffuser (commonly placed at the exit of the pipe-line) to the work plan or a point in this internal environment.

These searches are resulting predictive mathematical and computational models of the luminous efficiency by providing data on the luminous flux emitted by the environment in pipelines, and distributed illuminance on the working plane in lux. This allows the comparison of these systems with artificial lights and allows you to choose when you design with precise image scaling of the lighting system, allowing the association between daylighting and artificial lighting. The predictive models of light pipe efficiency have been developed by several researchers. S-DPF e E-DPF (Zhang, Muneer &Kubier, 2002), Universidade de Liverpool (Carter, 2002), Luxplots (Jenkins & Muneer, 2003), CIE Method (CIE 173, 2006). Dutton and Shao (2007) validate the software Photopia as a tool to predict the performance of pipelines, comparing this with six existing predictive methods (Wittwer, 1986; Swift & Smith, 1995; Edmonds, 1995 and Zhang et al, 2002, Jenkins & Muneer 2003, and Carters, 2002). This work presents the verification of a mathematical model for predicting the luminous efficiency of light-pipes (LEPMLP), in comparison with the results of raytracing simulation on Photopia software.

The LEPMLEP was based in the principle of projected solid angle or unit hemisphere. This principle is used by many graphic methods in order to obtain infor the sky component. Allowing the determination of its value even in situations in which the area of the luminous source is constituted by irregular forms (Hopkinson et al., 1975).

The objective of this paper is the use raytracing simulation (Photopia) to verify a mathematical simplified model that friendly estimates the light-pipe efficiency (LPE). For this, light -pipes were simulated in the software Photopia and tested under real sky conditions.

PREDICTIVE MODEL OF LUMINOUS EFFICIENCY OF LIGHT-PIPES (LEPMLP)

It was adopted the condition of uniform sky as source of daylight. The input section of the light-pipe is considered an emitter plane, which luminance is gathered in a horizontal unobstructed plan (considering a real situation).

The developed model predicts the value of the light-pipe efficiency (LPE), which is the ratio, in percentage, of illuminance in the output section and the available illuminance in the input section. The ratio is obtained through the sum of the illuminances in the output section of the light-pipe, arising from the luminance of the input section, as well as from the luminance of the reflected images in the mirrors, considering the successive losses due to absorption in the multiple reflections through the light-pipe.

The adopted procedure to consider the contribution of each image of the primary source (input section) is the projection of the images in the unit hemisphere considering the solid angle constituted by the input section and the centre point of the output section of the light-pipe. It's to say that luminance of the input section and its reflexions in the mirrors are delivered to the unit hemisphere.

The projected luminances in the unit hemisphere are in solid angles, constituting with the light-pipe vertical central axis angles (θi), which are the vertices of rectangles triangles, which base is the segment [(b.i)+b/2], where b is the input section length, and the height (h) is the length of the light-pipe. The value of the angle θi is determined by Equation 1.

$$\theta_i = atg\left[\left(i + \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right] \qquad (1)$$

where: i is the number of reflexions in the length of the pipe-light, or in other words, the number or images projected in the unit hemisphere; b is the input section length; h is the length of the light-pipe.

The projected luminances in the unit hemisphere produce circular sectors in the base of such hemisphere, which areas (Ai) (annulus) are defined by Equations 2 and 3.

$$a_i = \sin\theta_i \cdot r \qquad (2)$$

$$A_i = (a_i^2 - a_{i-1}^2) \cdot \pi \qquad (3)$$

where: Ai is the apparent area of the annulus; ai and ai-1 are the radius of the concentric circles determined by the projected luminances; r is the radius of the hemisphere (in this specific case, r=1).

Figure 1. Projected luminances in the unit hemisphere

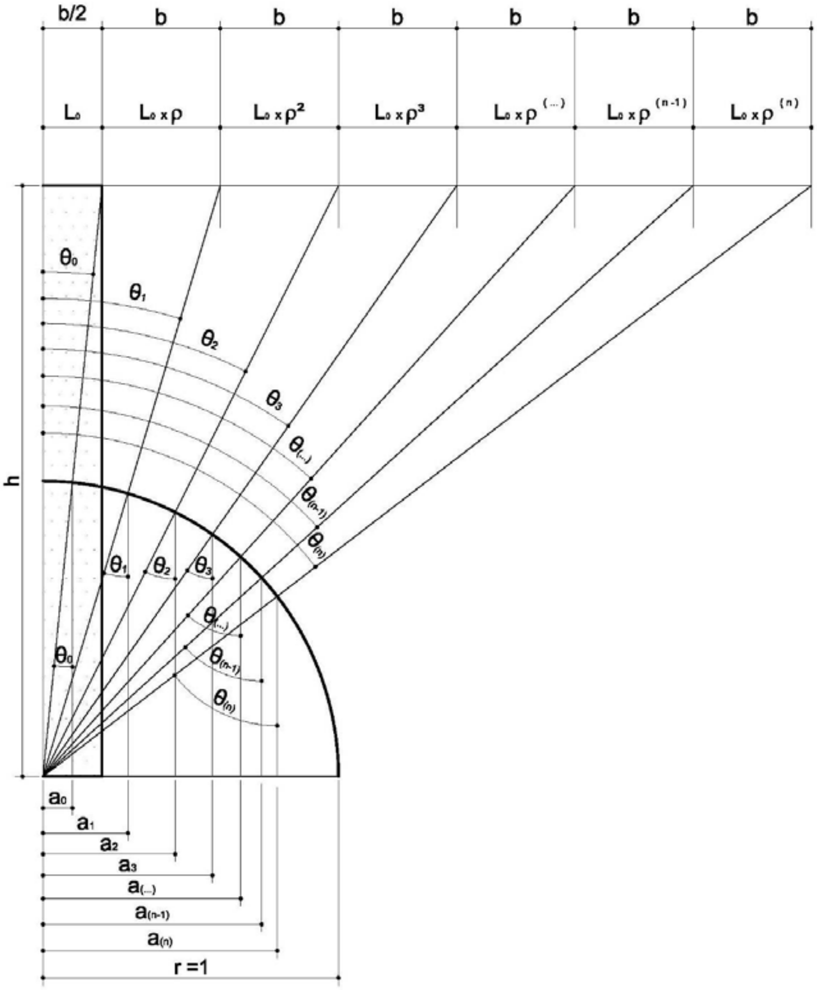
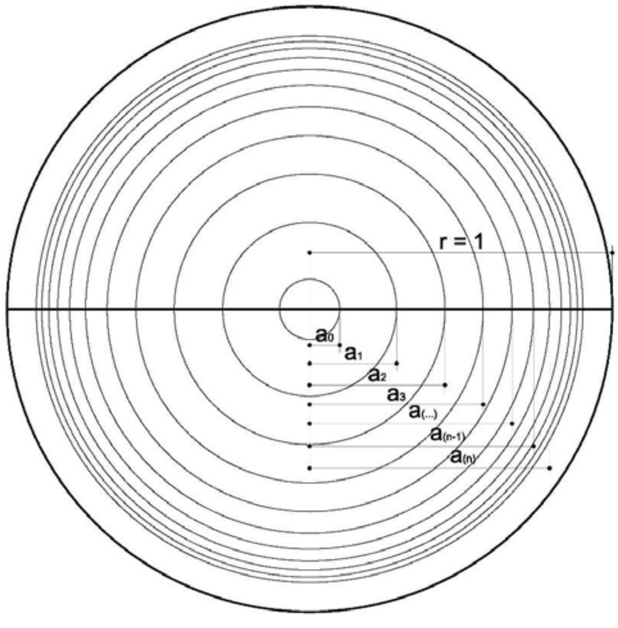


Figure 2. Annulus



The illuminance Ei is the contribution of each annulus. The sum of Ei for all annuli is the illuminance gathered in the central point of the output section, or it is to say, in the central point of the unit hemisphere. Ei is determined through Equation 4.

$$E_i = A_i \cdot L_0 \cdot \rho^i \qquad (4)$$

where: Ei is the illuminance of the annulus; Ai is the area of the annulus; L0 is the luminance in the light-pipe input section; ρ is the light-pipe internal reflectance. Considering the previous four equations, one may obtain the equation 5.

$$LPE = \frac{E_p}{E_{ext}} = \frac{\sum_{i=0}^{n} E_i}{\pi \cdot L_0} \qquad (5)$$

where: LPE is the light-pipe efficiency; Ep is the light-pipe output section illuminance; Eext is the available illuminance in the unobstructed horizontal plane; Ei is the annulus illuminance; L0 is the light-pipe input section illuminance; n is the number of the emitter plane reflections.

Mathematically, substituting equation 1 into 2, one obtains Equation 6.

$$a_i = \sin \cdot atg\left[\left(i + \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right] \qquad (6)$$

Substituting equation 6 into 3, one obtains Equation 7 and Equation 8.

When i = 0;

$$A_0 = \sin^2 \cdot atg\left(\tfrac{1}{2} \cdot \tfrac{b}{h}\right) \cdot \pi \qquad (7)$$

When i > 0;

$$A_i = \left\{\sin^2 \cdot atg\left[\left(i + \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right] - \sin^2 \cdot atg\left[\left(i - \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right]\right\} \cdot \pi \qquad (8)$$

Substituting equations 7 and 8 into 4, one obtains Equation 9 and Equation 10.

When i = 0;

$$E_0 = \sin^2 \cdot atg\left(\tfrac{1}{2} \cdot \tfrac{b}{h}\right) \cdot \pi \cdot L_0 \cdot \rho^0 \qquad (9)$$

When i > 0;

$$E_i = \left\{\sin^2 \cdot atg\left[\left(i + \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right] - \sin^2 \cdot atg\left[\left(i - \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right]\right\} \cdot \pi \cdot L_0 \cdot \rho^i \qquad (10)$$

Substituting equations 9 and 10 into 5, one obtains Equation 11, in order to predict the light-pipe efficiency (LPE).

$$LPE = \sin^2 \cdot atg\left(\tfrac{1}{2} \cdot \tfrac{b}{h}\right) + \sum_{i=1}^{n} \left\{\sin^2 \cdot atg\left[\left(i + \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right] - \sin^2 \cdot atg\left[\left(i - \tfrac{1}{2}\right) \cdot \tfrac{b}{h}\right]\right\} \cdot \rho^i \qquad (11)$$

The absolute values of LPE, obtained by equation 11, can be also considered in percentage values, as it is commonly used with the daylight factor (DF).

SOFTWARE SIMULATION

Photopia is a general 3D luminaire design and analysis program specifically designed for non-imaging and illumination optical systems. Photopia's calculation basis is probabilistic raytracing, using real lamp geometries and measured intensity distributions, as well as measured directional reflectance and transmittance data for luminaire materials. User specified analysis settings allow for quick or detailed analyses of the luminaire design. In addition, all calculated output is available for viewing as calculations are in progress via a display update facility. In this way, a user can observe evolving output as a function of a specified percentage of the total analysis process.

Photopia includes "lamp" models for use in modeling daylight input into devices such as skylights, light pipes, solar collectors and room windows using daylight control systems. These source (lamp) models are based on the IESNA RP-21 daylight equations that model the absolute illuminance from the sun (solar disk) at various altitude angles and the sky for various sky conditions and solar altitude angles. The sky domes include variable luminance values across the hemisphere as described in RP-21. The sun models include a 0.53 deg. spread in their beam to model the actual angular size of the solar disk, averaged over its elliptical orbit. The combination of both the sun and sky dome models produces a total illuminance onto the daylighting device area that is intended to match real outdoor conditions. Keep in mind that real conditions can vary widely and the RP-21 equations represent average conditions. Such variability is what makes consistent physical measurement of daylight devices such a challenge and is one reason why daylight simulation is desirable.

Using the daylight source models is different than using the electric lamp models in Photopia's library since the daylight models illuminate the outside of a device to get light into it instead of illuminating a luminaire from within.

The default sky dome models are configured so that they uniformly illuminate about a 4' diameter area. Because of the way the light is emitted from the sky dome patches, light does spread beyond this 4' circle but it fades to a much lower level. In order to fully illuminate your device and also maximize the portion of sky dome rays that enter your device this model should also be scaled up or down depending on your device size relative to this 4' circular reference.

Since the sun and sky dome models will produce some rays that don't enter the daylight collection device, the complete model generally needs to include a shield so that the output of the device is isolated from the source models' stray light. The sky domes are relatively large in diameter since they need to generate a relatively even illuminance over an area large enough to accommodate the daylighting device. They concentrate most of their light toward the center of the hemisphere, but some light also strays away from the center. Only that light falling near the center of the hemisphere accurately models the way light is received from the sky dome.

The sky domes are relatively large in diameter since they need to generate a relatively even illuminance over an area large enough to accommodate the daylighting device. They concentrate most of their light toward the center of the hemisphere, but some light also strays away from the center. Only that light falling near the center of the hemisphere accurately models the way light is received from the sky dome. A lot of the light generated by the sky dome will not enter the daylighting device so it is also important to trace a large number of rays so that good resolution in your results can be obtained.

The efficiency (LOR) shown in the Photopia report will be the ratio of the lumens exiting the skylight divided by the total lumens produced by the sun and sky dome models. The total lumens produced by the sun and sky dome models is very large compared to the total number of lumens that are actually incident onto the daylight device. A more appropriate measure of the device efficiency is the ratio of the lumens exiting the device divided by the number of lumens incident onto it.

The studies presented by DUTTON & SHAO (2007) showed good results in using this software for predicting the performance of pipelines bright light compared to existing mathematical models. The simulations presented here, aimed to predict the transmittance of light through light pipes. For both pipe-lines were simulated with 36 input section ranging from 10cm, 20cm, 25cm, 30cm, 40cm and 50cm and lengths ranging from 1m, 1.5m, 2m, 3m, 4m and 5m.

DATA TREATMENT

Photopia provides a photometric report in which the luminous flux emitted by the luminaire is given. This report also shows the efficiency of the light, but in the case of the pipeline. This efficiency is false because the Photopia calculates it based on total luminous flux produced by the light source, in which case the pipe-line is the celestial vault. Thus, the value of the efficiency of a lamp is always the ratio between the total fixture lumens coming out of the total lumens generated by the sources (lamps) . In the case of designs that use daylight, this result does not match the efficiency of the lamp itself, in order that the source light does not emanate from within the machine but from outside. Thus, as only a small fraction of this light is captured through the pipe-line, the calculated result is usually negligible.

Therefore, it is necessary to know the value of the luminous flux that actually enters the pipe-line so that one can calculate the correct efficiency. To calculate the luminous flux entering the pipe-line light is necessary to calculate the horizontal illuminance at the opening of the pipe-line (lm/m^2) and multiply it by the area of the opening.

Photopia provides an Excel spreadsheet for this calculation. This is the "Daylighting Calculator" option that is on the menu "Help". This tool provides two options for sky condition , with sun or no sun and two choices of units of measure to be chosen , the international system and the Imperial system for the simulations was chosen the international metric system , the units are in meters , lumens and lux . For these simulations we used the "Enter Altitude Solar" option because this option, simply enter the angular position of the sun and the area of the inlet opening of the collector, the spreadsheet calculates the luminous flux entering the pipe-line.

The Daylighting Calculator spreadsheet only requests diameter header pipe because it is assumed that the shape of the device is round. As the simulated pipe-lines were square in section, the area of the section was calculated and then multiplied by the value of the horizontal illuminance average daylight in the pipe-line. The average horizontal illuminance is calculated by the referred spreadsheet.

$$\phi_{in} = E_{média} \cdot A \tag{12}$$

Where: φin is the total luminous fluz entering the pipeline; Emédia is the mean horizontal iluminance; A ia the entrance área of the pipeline.

Having obtained the luminous flux input, calculated by "Daylighting Calculator" (φin), the value of the total flux emitted by the product of light at the end of the simulation (φout) Photometric report and calculate the efficiency of the light pipe (in terms of percentage) by the following equation.

$$E = \frac{\phi_{out}}{\phi_{in}} \cdot 100 \tag{13}$$

where: E is thelight-pipe efficiency (LPE); φout is the luminous flux from the light pipe.

MEASUREMENTS

For the empirical research nine light-pipes, made of wood coated by mirror (optimirror plus, reflectance ρ=0,86), with square sections of 10cm, 25cm and 40cm e lengths of 100cm, 150cm and 200cm were considered.

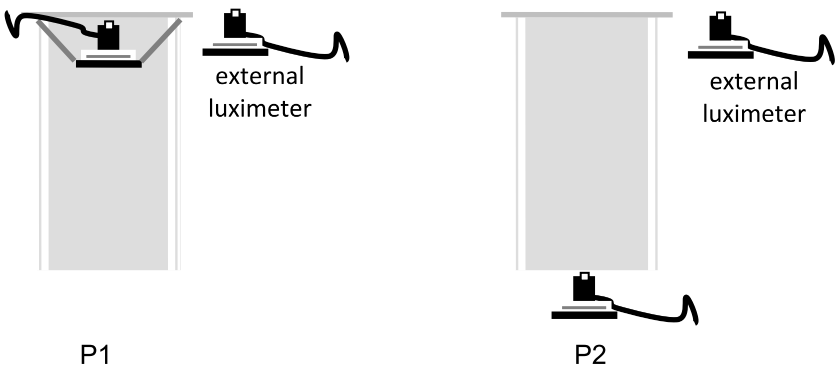
The mathematical model considers a theoretical uniform sky, thus in order to approximate the conditions of a real sky to the considered model, it was considered a real unobstructed overcast sky through the use of acrylic diffusers in the input section of the light-pipes.

The empirical field researches were done during 22/04/2009 and 06/05/2009.

Figure 3. Light-pipes of the empiric field research.

In order to log the data, digital luximeters HOMIS model 824 were used. They were set in the central spot of the input and output section of the light-pipes (respectively P1 and P2 in Figure 4). The data were collected in each point and each light-pipe one at a time, considering, as a reference, an external luximeter, measuring simultaneously the unobstructed horizontal plane.

Figure 4. Schematic illustration of luximeters positioning



COMPARATIVE RESULTS

The results obtained in the simulations with 36 pipelines were compared with a real scale model under real sky condition (LUZ, 2009) and with results calculated using the luminous efficiency of light pipes predictive model (MPELD. These comparisons are presented in the following figures.

Figure 5. Correlation between predicted and measured LPE (light-pipe efficiency).

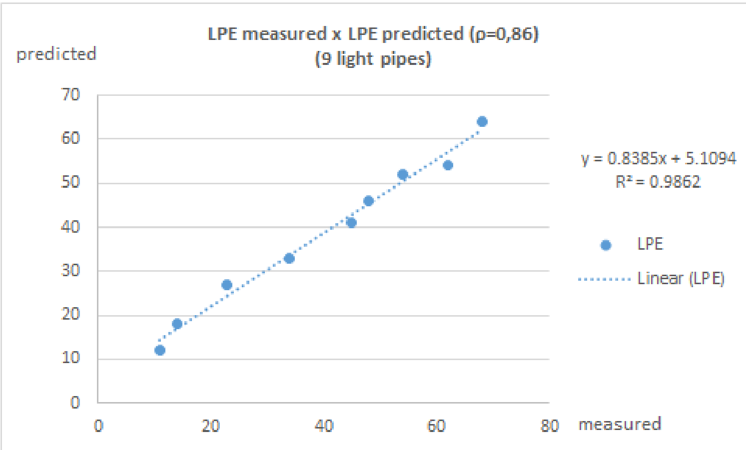


Figure 6. Correlation between predicted and simulated LPE (light-pipe efficiency).

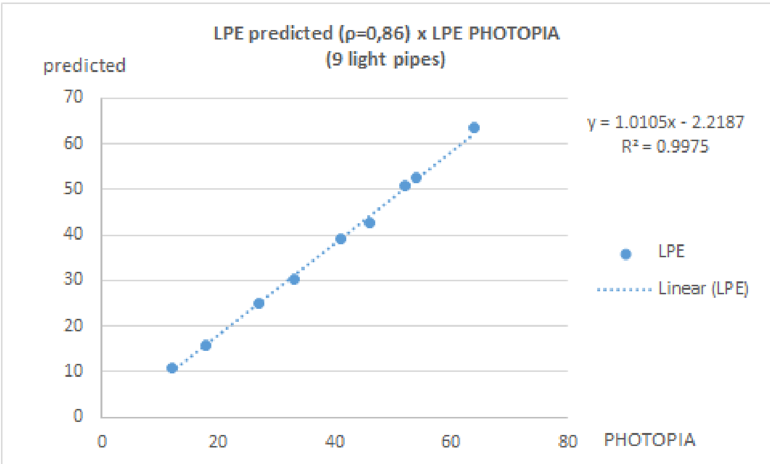
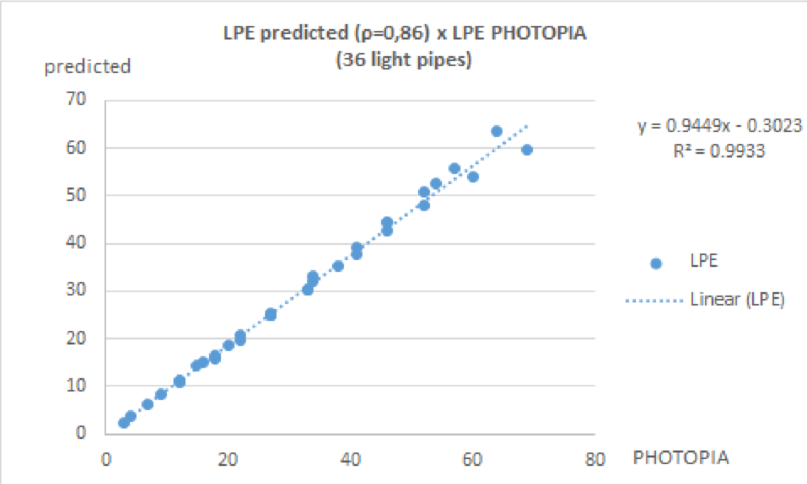


Figure 7. Correlation between predicted and simulated LPE (light-pipe efficiency).



CONCLUSION

The high correlation found between results from the measured data and results from the proposed luminous efficiency predictive model of light-pipes (LEPMLP) with the results obtained from the software Photopia, in terms of estimated values of light-pipes efficiency (LPE), showed that the model is a reliable tool and is easily applicable for dimensioning light-pipes, taking advantage of daylighting in everyday architectural and building design practice, allowing to deliver daylight to rooms without direct contact with the external environment.

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Development of a High-resolution Meteorological Model for Urban Heat Island Effect Assessment

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ABSTRACT

Facing rapid urbanization, sustainable urban developments become important in urban planning. To tackle urban climate issues in a planning context, a meteorological model with high resolution is useful for evaluating different planning scenarios. This study used the Weather Research and Forecast (WRF) with a single-layer urban canopy model to simulate summer meteorological conditions in Hong Kong, downscaling the spatial resolutions from 4.5 km to 500 m. Hong Kong (HK) was taken as an example due to its high building density in a sub-tropical climate region. The model results were compared against measurements at 25 weather stations. We quantified the urban heat island effect (UHI) in the summer in 2009, and estimated the resultant health impacts based on a temperature-response function. The model results and measurements show a good agreement with an index of agreement of 0.71 and a percentage difference of mean temperature of 1.33%. Our analysis estimated that the hourly temperature in urban areas (29.6℃) is higher comparing to that in rural areas (28.1℃). The Urban Heat Island Intensity (UHII) was estimated to be 1.6℃ on average. The UHI results in different Primary Planning Units show a north-south gradient pattern over Hong Kong: the highest UHII (1.7℃) in northern part of HK, whereas the lowest UHII (0.8℃) in southern part of HK. We found UHII correlates well with urban area size instead of population, highlighting that policy makers of high-density cities should pay attention to urban area size when tackling UHI. In addition, UHI was estimated to cause 75 [95%C.I. 22-158] mortalities in summer. Of which, ~55% of the UHI-related health impact occurs in New Territories, while 39% and 6% of the impact happen in Kowloon and Hong Kong Island, respectively. The results provide critical implications for urban planners to mitigate UHI in cities, especially in less developed countries.

NOMENCLATURE

PPU	Primary Planning Units
TPU	Tertiary Planning Units
UHI	Urban heat island effect
UHII	Urban Heat Island Intensity

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WRF the Weather Research and Forecast model

INTRODUCTION

Urban heat island effect (UHI) is one of the major environmental problems in urban areas. Increases in temperature were found to have impacts on energy consumptions, public health and even air quality (Sarrat et al., 2006). According to the United Nations (2012), total urban population is projected to increase to ~67%. Thus, it is of importance to understand the urban heat island effect and the resultant impacts, especially in high-density cities such as Hong Kong (HK) given that the urban infrastructure and building morphology play an important role in the UHI (Rizwan et al., 2008).

Previous studies have shown that UHI was observed in Hong Kong. Memon et al. (2009) examined the reliability of urban heat island intensity (UHII), which was defined as the temperature difference between urban and rural areas. Based on the measurements collected at six weather stations, the study estimated that the mean hourly UHII ranged between 0.8℃ and 2.0℃. Giridharan et al. (2004 and 2005) investigated the UHI in urban high-density residential developments in both daytime and nighttime. Based on the measurements on several selected days in the summer in 2002, Giridharan et al. estimated that the magnitudes of UHI within an estate were 1.5℃ and 1.3℃ in daytime and nighttime, respectively. Although the UHI was estimated in the previous studies, the majority of the studies were based on measurements at sparsely-distributed locations. Thus, the spatial distribution of UHI and the resultant impacts have not yet been fully understood.

Changes in ambient temperature due to UHI may cause heat-related mortality, especially in summer. The health impacts of extreme hot weather events such as heat wave were previously studied (Bai et al., 2014; Zeng et al., 2014; Amengual et al., 2014). For Hong Kong, Chan et al. (2010) employed a statistical approach to investigate the relationship between the heat-related mortality due to changes in ambient temperature. However, the mortality due to UHI was not calculated in the study.

Therefore, this study is aimed at estimating the magnitude of summer UHI in Hong Kong and the resultant heat-related mortality. The results are anticipated to provide critical implications for urban planners and authorities to mitigate UHI in cities, especially for the ones which are being developed in less developed countries such as mainland China.

METHODS

Meteorological Model

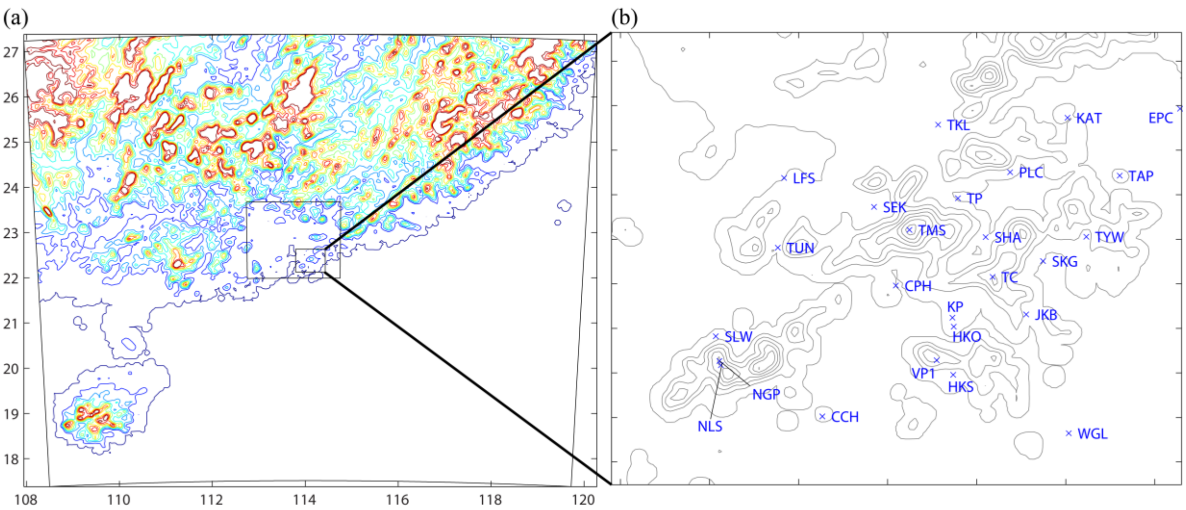

Figure 1 (a) The three WRF simulation domains. (b) The locations of the 25 HKO monitoring stations. The station names are provided in Table 1.

In this study, two months (Jul and Aug, 2009) were selected to investigate the summer UHI in HK. The Weather Research and Forecast model (WRF) (Skamarock et al., 2008) was used to reproduce the spatial distribution of temperature over Hong Kong in the study period. The WRF model has been widely used in urban heat island studies (Chen et al., 2014; Giannaros et al., 2013; Salamanca et al., 2012; Yang et al., 2012). The WRF model was configured to have three one-way domains, using which the meteorology was downscaled from a regional scale to a local scale. Figure 1(a) depicts the WRF domains. The outermost domain (D1) covers most of Guangdong province. D1 has 264×240 grid points with a spatial resolution of 4.5 km. The results of the D1 were then downscaled to the second domain (D2), which encompasses the Pearl River Delta. D2 has 136×124 grid points with a spatial resolution of 1.5 km. The innermost domain (D3) covers Hong Kong. D3 has 130×112 grid points with a spatial resolution of 500 m. A single-layer urban canopy model was adapted to improve the lower boundary conditions and the WRF performance within the urban regions (Masson, 2000). The WRF was configured to have 34 vertical sigma levels from the ground to the model top (50 hPa), with the first 11 layers being concentrated in the first 1 km above the ground level to resolve the structure of meteorology in the planetary boundary layer.

Table 1. The Names and Labels of the 25 Hong Kong Observatory Stations. The Locations of the Stations Are Shown in Figure 1(b).

	Station name	Label		Station name	Label		Station name	Label
1	Cheung Chau	CCH	**11**	Tai Mei Tuk	PLC	**21**	Tuen Mun	TUN
2	Ching Pak House	CPH	**12**	Shek Kong	SEK	**22**	Tsak Yue Wu	YW
3	Ping Chau	EPC	**13**	Sha Tin	SHA	**23**	The Peak	VP1
4	Wong Chuk Hang	HKS	**14**	Sai Kung	SKG	**24**	Waglan Island	GL
5	Tseung Kwan O	JKB	**15**	Sha Lo Wan	SLW	**25**	HKO	HKO
6	Kat O	KAT	**16**	Tap Mun	TAP			
7	King's Park	KP	**17**	Tate's Cairn	TC			
8	Lau Fau Shan	LFS	**18**	Ta Kwu Ling	TKL			
9	Ngong Ping	NGP	**19**	Tai Mo Shan	TMS			
10	Nei Lak Shan	NLS	**20**	Tai Po	TP			

Multiple WRF simulations were conducted with a length of each simulation not exceeding a seven-day period. The results of first 24 hours were discarded as a spin-up period. The land use data was provided by the Lands Department of Hong Kong. The initial and boundary conditions were provided by the $1°\times1°$ NCEP FNL (Final) Operational Global Analysis data (NCEP, 2000) at six-hour intervals.

Measurement data to evaluate the WRF model were provided by the Hong Kong Observatory (HKO). The HKO stations are listed in Table 1 and plotted in Figure 1(b). To quantify the model performance, a set of statistical measures was computed similar to Yim et al. (2007; 2012; 2013).

The UHI was quantified by the Urban Heat Island Intensity (UHII), which represents the temperature difference between urban and rural areas. In this study, non-urban areas (except water bodies) were defined as rural areas. Both hourly and two-monthly mean UHII were estimated based on the WRF outputs. Figure 2 depicts urban areas (brown), non-urban areas (green) and water bodies (blue) in Hong Kong.

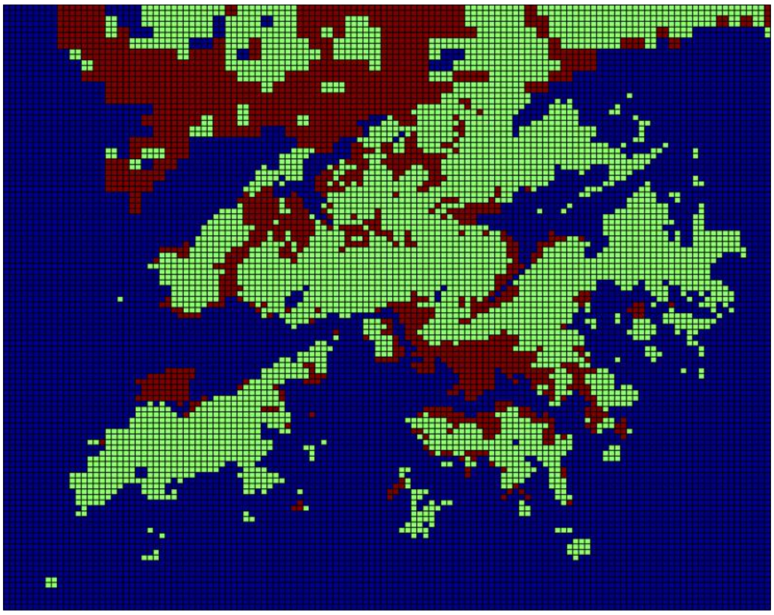

Figure 2 A land use map for urban areas (brown), non-urban areas (green) and water bodies (blue) in Hong Kong.

Health Impact

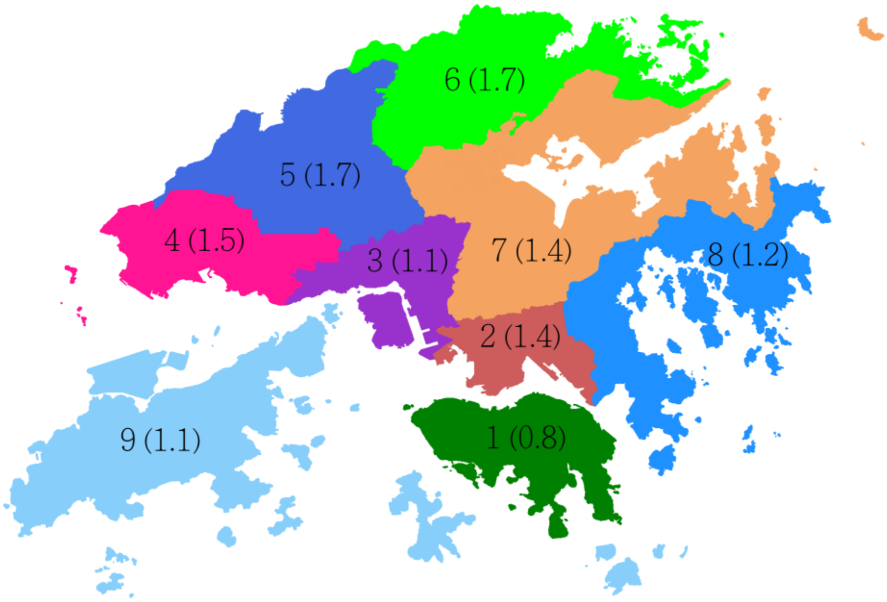

Figure 3 The nine Primary Planning Units (PPU) in Hong Kong. The PPU numbers are marked in the figure. New Territories includes PPUs 3, 4, 5, 6, 7, 8 and 9. Kowloon includes PPU 2, while Hong Kong Island includes PPU 1. The urban heat island intensity (UHII) (°C) values are provided in the brackets.

The health impact due to UHI was estimated based on the Chan et al. (2010). Their study estimated that 1.83% (95% C.I.: 0.73%-3.00%) increase in mortality in Hong Kong is associated with an average of 1°C temperature increase in daily mean temperature above 28.2°C. In their study, the increase of relative risks of heat-related mortality in different areas of residence including Hong Kong Island, Kowloon, New Territories and others were estimated to be 1.43% (95% C.I.: -1.20%-4.30%), 1.36% (95% C.I.: -0.63%-3.47%), 1.40% (95% C.I.: -0.53%-3.43%) and 9.27% (95% C.I.: 1.93%-18.17%), respectively. The areas of residence are depicted in Figure 3.

To estimate the population-exposure to UHI, the daily mean temperature of each day in the study period was overlaid onto the population data in a Tertiary Planning Units (TPU) level provided by the Hong Kong Planning Department. The average daily mortality per 1,000 persons was derived by dividing the annual mortality rate (6.1 deaths per 1,000 persons) provided by the Centre for Health Protection (2012) by 365 days. Thereafter, based on the aforementioned temperature-response function (Chan et al. 2010), the resultant mortality was estimated. We note that the temperature in indoor environments and the influence of population daily mobility were not taken into account in this study due to lack of data that may result in a higher bias in our results.

Uncertainty

For all the input data in the heat-related mortality calculation, an uncertainty distribution was estimated based on a Monte Carlo simulation, in which a triangular distribution of estimates was constructed on the basis of 10,000 samples. Uncertainty bounds were for a 95% confidence interval.

RESULTS

Model Evaluation

Figure 4 depicts time series plots of temperature at 2 m above ground at two HKO stations: HKO (urban) and TKL (rural). The results show that the modelled temperature agrees well with the measurements. As shown in Table 2, the index of agreement of temperature is 0.71 on average. The percentage difference of mean temperature is 1.33%, indicating that the simulation results are promising for our analyses in this study.

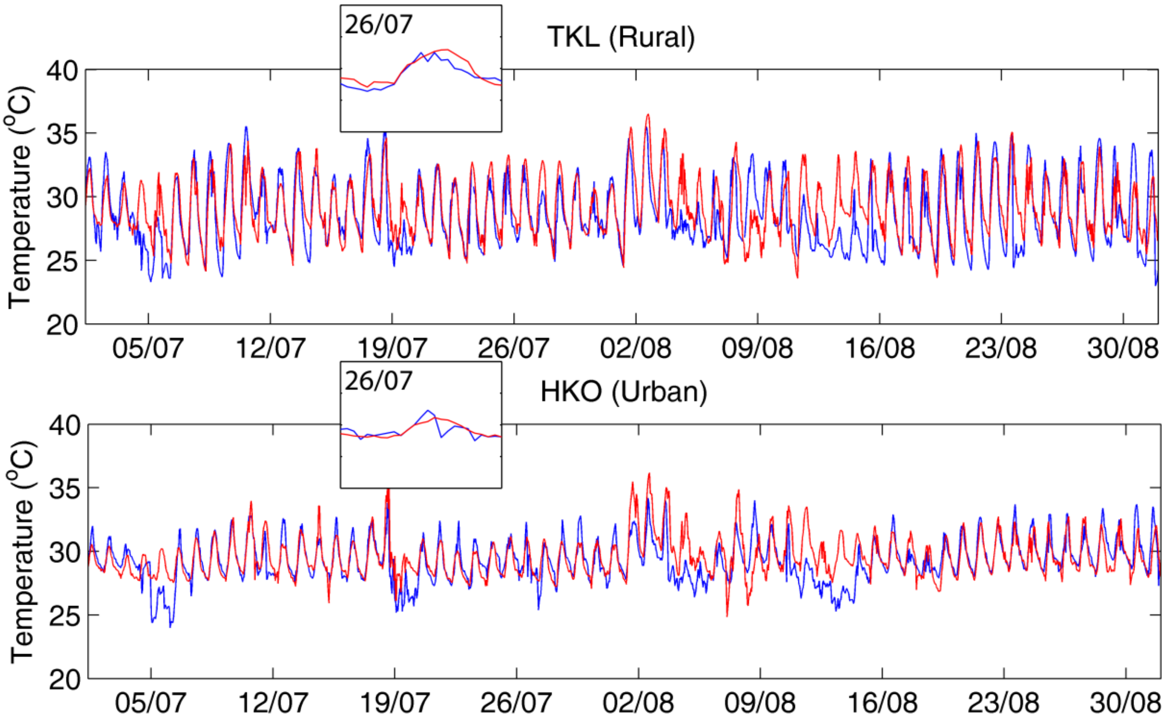

Figure 4 Time series plots of model evaluation of hourly temperature at 2 m above ground at Ta Kwu Ling – TKL (rural) and Hong Kong Observatory – HKO (urban). Blue lines represent observation data, whereas red lines represent model results. The two small figures are zoomed for a randomly-selected day (26/07) for clarity. The locations of the two stations are shown in Figure 1(b).

Table 2. The Statistical Measures of Model Evaluation. Obs: Observation; IOA: Index of Agreement; Corr: Correlation coefficient; RMSE: Root Mean Square Bias; MB: Mean Bias; MNB: Mean Normalized Bias; NMB: Normalized Mean Bias; MFB: Mean Fractional Bias; ME: Mean Error; NME: Normalized Mean Error; MNE: Mean Normalized Error; MFE: Mean Fractional Error; MPD: Mean Percentage Difference; DA: Data Availability.

	Model		Obs														
Station name	Mean (℃)	SD (℃)	Mean (℃)	SD (℃)	IOA	Corr	RMSE (℃)	MB (%)	MNB (%)	NMB (%)	MFB (%)	ME (℃)	NME (℃)	MNE (℃)	MFE (℃)	MPD (%)	DA (%)
CCH	28.7	1.1	28.2	2.0	0.6	0.5	1.8	0.5	2.3	2.0	2.1	1.4	5.0	5.0	5.1	2.0	99.9
CPH	28.9	1.6	29.2	1.8	0.8	0.6	1.5	-0.3	-0.8	-0.9	-0.9	1.2	4.0	4.0	4.0	-0.9	99.9

EPC	28.9	0.9	28.4	2.0	0.5	0.3	2.0	0.5	2.3	1.9	2.0	1.7	5.8	5.8	5.9	1.9	84.0
HKO	29.6	1.6	29.2	1.7	0.8	0.6	1.4	0.3	1.2	1.1	1.1	1.0	3.4	3.4	3.5	1.1	100.0
HKS	28.9	1.4	28.9	1.8	0.7	0.6	1.5	0.0	0.2	0.0	0.0	1.2	4.0	4.0	4.1	0.0	99.9
JKB	28.2	1.7	28.7	2.3	0.8	0.7	1.8	-0.4	-1.2	-1.5	-1.3	1.4	4.9	4.8	4.8	-1.5	99.9
KAT	29.1	1.1	29.0	2.1	0.6	0.4	2.0	0.1	0.7	0.3	0.5	1.5	5.0	5.0	5.0	0.3	96.8
KP	29.7	1.7	29.0	1.8	0.8	0.6	1.6	0.6	2.4	2.2	2.2	1.2	4.0	4.0	4.1	2.2	97.5
LFS	29.2	1.2	28.8	2.1	0.6	0.5	1.9	0.4	1.9	1.6	1.7	1.5	5.2	5.2	5.3	1.6	99.9
NGP	25.4	1.5	23.5	1.0	0.5	0.4	2.4	1.9	8.1	8.0	7.6	2.0	8.4	8.0	8.5	8.0	99.0
NLS	25.3	1.5	24.2	1.9	0.7	0.6	1.9	1.1	4.9	4.6	4.6	1.6	6.5	6.4	6.6	4.6	95.7
PLC	29.0	1.7	28.8	2.3	0.8	0.6	1.8	0.2	1.2	0.8	1.0	1.3	4.6	4.6	4.6	0.8	98.1
SEK	29.8	2.0	29.1	2.5	0.8	0.7	2.0	0.7	2.7	2.3	2.4	1.5	5.2	5.2	5.4	2.3	99.8
SHA	29.9	1.9	29.6	2.1	0.8	0.7	1.7	0.3	1.2	1.0	1.0	1.2	4.1	4.1	4.2	1.0	99.8
SKG	28.9	1.6	29.3	1.9	0.8	0.6	1.6	-0.4	-1.1	-1.3	-1.2	1.3	4.3	4.3	4.3	-1.3	99.9
SLW	29.0	1.7	28.8	2.0	0.8	0.6	1.7	0.2	0.9	0.7	0.8	1.2	4.3	4.3	4.4	0.7	99.9
TAP	29.1	1.0	29.2	2.4	0.5	0.4	2.1	-0.1	0.2	-0.4	-0.1	1.7	5.9	5.9	5.9	-0.4	82.6
TC	25.4	1.6	25.1	2.0	0.8	0.6	1.6	0.3	1.5	1.2	1.3	1.2	4.7	4.7	4.7	1.2	99.4
TKL	29.1	2.3	28.5	2.7	0.8	0.7	2.0	0.6	2.3	2.0	2.1	1.5	5.3	5.3	5.4	2.0	99.8
TMS	23.8	1.4	22.4	1.3	0.7	0.6	1.8	1.4	6.3	6.2	6.0	1.6	6.9	6.7	7.0	6.2	98.3
TP	29.8	1.9	28.7	2.0	0.7	0.6	2.0	1.1	4.0	3.8	3.8	1.5	5.4	5.3	5.5	3.8	99.9
TUN	29.7	1.8	29.7	2.0	0.8	0.6	1.8	0.1	0.4	0.2	0.3	1.3	4.5	4.5	4.6	0.2	99.8
TYW	28.9	1.7	28.0	2.9	0.8	0.7	2.2	0.8	3.6	3.0	3.3	1.8	6.4	6.4	6.6	3.0	96.0
VP1	26.2	1.5	26.1	1.7	0.8	0.6	1.4	0.0	0.3	0.1	0.1	1.0	4.0	3.9	4.0	0.1	93.9
WGL	28.7	0.6	28.8	1.8	0.3	0.1	1.8	-0.1	0.1	-0.3	-0.1	1.4	4.8	4.8	4.8	-0.3	99.9

Temperature Differences between Urban and Rural Areas

Figure 5 depicts the hourly temperature distributions in urban (red) and rural (blue) areas. The results show that the hourly temperature in urban areas (29.6℃) is higher comparing to that in rural areas (28.1℃).

Chan et al. (2010) has found that a unit change in temperature in daily temperature above 28.2℃ is associated with an increase in relative risk of heat-related mortality. Thus, 28.2℃ was defined as a critical temperature in this study. Figure 6(a) depicts the daily temperatures in urban and rural areas. We estimated that the daily temperature in urban areas is always (>98%) higher than the critical temperature. However, only ~35% of the time the daily temperature in rural areas exceeds the critical temperature. The mean daily temperature in rural areas was found to be 28.1℃, which is slightly lower than the critical temperature. As shown in Figure 6(b), the mean UHII was estimated to be 1.6℃ on average.

Figure 3 depicts the UHII in different Primary Planning Units (PPU). In the figure, a north-south UHI gradient pattern is shown. We estimated that the magnitude of UHI (1.7℃) in northern part (PPU 5 and PPU 6) of HK is the highest among the PPUs. The urban population of the both PPUs, when combined, accounts for 12.6% of the total urban population in HK. The lowest UHI (0.8℃) was estimated to occur in PPU 1, which is located at the southern part of HK. The PPU 2, where its population accounts for 29.6% of total urban population in HK, was estimated to have 1.4℃ UHI.

Our estimate shows that the intensity of UHI correlates well with the size of urban areas instead of population. Hong Kong is a high building-density and high-population density city (Ng et al., 2012) due to limited lands for development, and thus its population is not proportional to the size of urban areas. Despite a lower population such as PPU 5 which accounts for only 8.2% of the total HK population, a larger urban area receives more solar radiation and may therefore result in a higher UHII. On the other hand, it should be highlighted that the urban area size pattern is consistent with the UHII pattern as observed in Figure 3. Figure 7 depicts that PPU 5 and 6 have a larger urban area, while PPU 1, 8 and 9 have a smaller urban area. This result indicates that the north-south UHI gradient pattern is associated with the pattern of urban area size.

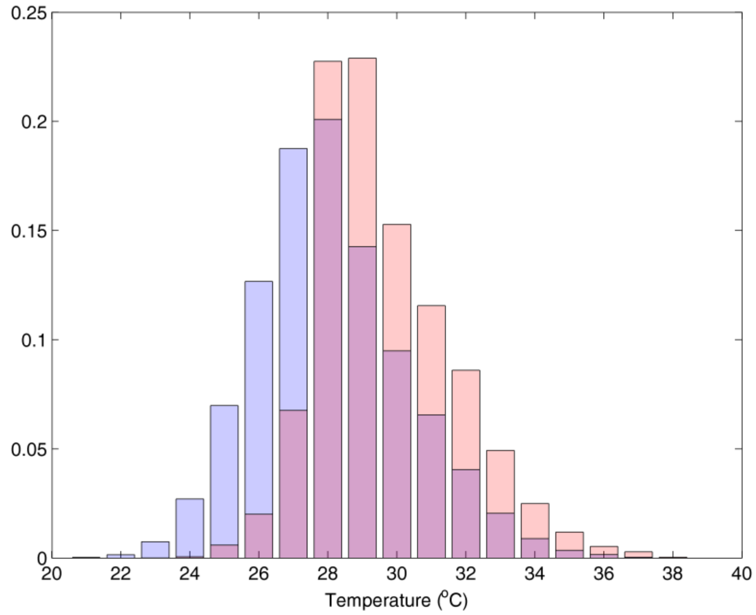

Figure 5 The frequency distribution of hourly temperature in rural (blue) and urban (red) areas in the study period. The x-axis represents temperature (°C), while y-axis represents normalized frequency.

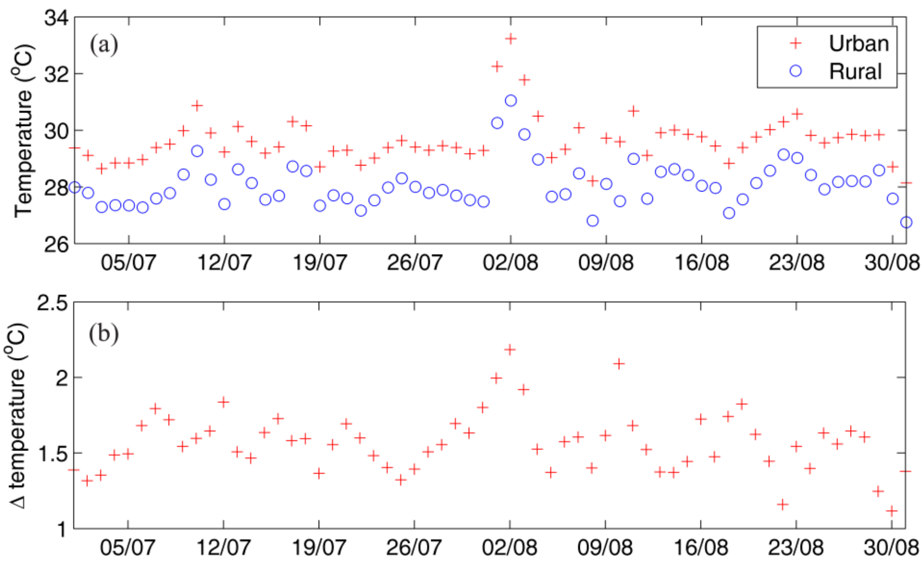

Figure 6 (a) The time series of daily mean temperature (℃) at 2 m above ground in urban (+ in red) and rural (o in blue) areas. (b) The time series of daily urban heat island intensity (UHII) in the study period.

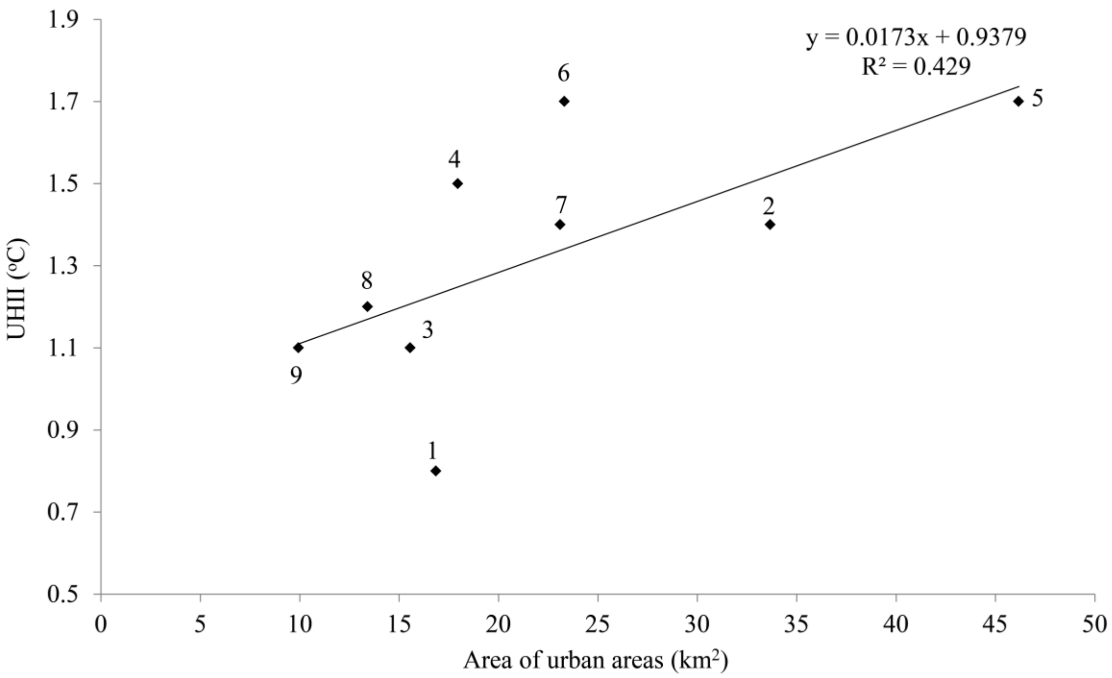

Figure 7 the relationship between area of urban areas (km^2) and urban heat island intensity (UHII) (^oC). The numbers near the data points represent the corresponding Primary Planning Unit number.

Health Impacts

We estimated that UHI causes 75 [95%C.I.: 22-158] mortalities in HK in summer, indicating that ~38 [95%C.I.: 11-79] mortalities are more likely associated with UHI each month in summer. The results show that ~55% of the UHI-related health impact occurs in New Territories, while 39% and 6% of the impact happen in Kowloon and Hong Kong Island, respectively.

DISCUSSIONS

Our results show that HK is affected by UHI in summer, where the mean hourly UHII is 1.6℃. This estimate is consistent with Memon et al. (2009), in which mean hourly UHII was estimated to range between 0.8℃ and 2.0℃. According to Leung et al. (2004), the temperature increase rates at an urban station (HKO) and a rural station (TKL) from 1989 to 2002 were estimated to be 0.61℃ and 0.15℃ per decade. The different increase rate between urban and rural areas indicates that the magnitude of UHI and the resultant health impact may increase in the next decade. Thus, mitigation measures should be implemented to address the UHI. Previous research has studied different mitigation measures such as green roof (Coutts et al., 2013; Zhao et al., 2014), vertical greening (Perini et al., 2011; Tan et al., 2014), and root coating (Bretz et al., 1997). On the other hand, Cheung et al. (2012) showed the importance of air ventilation for enhancing thermal comfort in a city.

Chen et al. (2010) reported that some sensitive groups such as the elderly may be more vulnerable to heat-related mortality. However, age distributions were not taken into account in our estimation due to lack of data. Therefore, more investigations should be done to further estimate the UHI-related mortality among different groups within urban community. In addition, we note that anthropogenic heat emissions, which could play an important role in the formation of UHI, were not taken into account in this study due to lack of the corresponding data. The lack of anthropogenic emisisons may cause a lower bias of our results. Nevertheless, this work identified the UHI and its health impacts due to land use variations (urban vs rural).

Another important impact of UHI is additional energy consumption. Fung et al. (2005) studied the energy consumption due to increase in urban temperature of Hong Kong. Based on the data from 1990 to 2004, the study estimated that the energy cost in summer due to an increase in 1℃ ambient temperature would increase by HK$1.6 billion per year. The study showed an important relationship between the additional energy consumption due to change in ambient temperature. However, the change in energy consumption due to UHI has not been studied in the literature, and thus needs to be quantified in a global change adaption context in the future work.

CONCLUSION

In this study, we quantified the urban heat island effect (UHI) in the summer in 2009 and estimated the resultant health impacts based on a temperature-response function reported in the literature. Our analysis estimated that the hourly temperature in urban areas (29.6℃) is higher comparing to that in rural areas (28.1℃). The Urban Heat Island Intensity (UHII) on average. The UHI results in different Primary Planning Units show a north-south gradient pattern over Hong Kong: the highest UHII (1.7℃) in northern part of HK, whereas the lowest UHII (0.8℃) in southern part of HK. We found that UHII correlates well with urban area size instead of population, indicating that policy makers of high-density cities should pay attention to urban area size when tackling UHI. In addition, UHI was estimated to cause 75 [95%C.I. 22-158] mortalities in summer. Of which, ~55% of the UHI-related health impact occurs in New Territories, while 39% and 6% of the impact happen in Kowloon and Hong Kong Island, respectively. The results provide critical implications for urban planners to mitigate UHI in cities, especially for the ones which are being developed in less developed countries such as mainland China.

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Sustainability Assessment Methods for the Gulf Region

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ABSTRACT

This paper describes the development of a sustainability assessment framework designed to be used in the Gulf Region, which is an area which has experienced large scale building development and also a region in which sustainability assessment is not yet widely used. The complexity and time resources needed to apply existing methods act as a deterrent to active use. Three well-known methods available at the time of the study were investigated in some detail. These were: BREEAM Gulf; Green Building Council LEED; and Estidama Pearl. Cross comparisons of the factors involved in each method were carried out on several levels including: theoretical comparison; practical development and usability; compliance with regulations and standards; and ability to achieve synchronization. A considerable degree of compatibility was found to exist between the methods, particularly if focused on key criteria. As a result a new and specific framework was developed which grouped 24 indicators under five principal headings: site/location, biodiversity and accessibility; energy; water; occupant well-being; and resources and wastes. This new framework was then evaluated by testing with practitioners resulting in confirmation of 20 out of the 24 indicators, and identification of suitable benchmarks.

INTRODUCTION

The Arabian Peninsula is located in a hyper-arid zone, apart from the oil and gas there are minimal natural resources (Galbraith 2008) and the volume of construction work in the region, and Dubai in particular, has been unprecedented. There are impacts on many levels: economic; regional investment; and more specifically on the real estate sector. Dubai in particular has developed some astounding architecture and demonstrates inspiring achievements in form, scale, and budget. However and consequently, the construction industry has laid a heavy burden on natural resources (Al Marashi, 2006).

The Gulf region countries as a group are popularly referred to as the ‘The Gulf Cooperation Council’ (GCC) countries, consisting of: Saudi Arabia, Bahrain, Kuwait, Qatar, the United Arab Emirates, and Oman, with a total population estimated as 46.8 million. At the regional level, the characteristics that are common to the six countries reflect their similar rapid economic expansion, but they also originate from the fact that power generation in the six countries is mainly oil and gas based.

The energy sector, has played a crucial role in the socio-economic development of the GCC countries and also plays a significant role in economic growth and in development of policies towards environmental and sustainability issues in the GCC (Al Zubaidi, 2007).

Meanwhile sustainable buildings construction is still very limited in the region compared to the total building market and as a consequence, their cumulative impact on the reduction of ecological footprint is currently almost negligible. Recognizing the poor ecological situation, a study by Lahn, Stevens and Preston (2012) estimated a 29% potential energy saving in the building sector by 2025 (the

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highest among all sectors potential savings) if effective efficiency measures were followed. There is a however reluctance to take up environmental assessment methods in the region; barriers encountered are varied in their type and magnitude. A general lack of understanding, and the level of complexity found in the methods are attitudes reflecting the main issues of concern. There is a need to develop more sophisticated targeted evaluation techniques and to limit the number of prescribed indicators to those of high sensitivity in a more effective basic environmental assessment for buildings in the Gulf region.

An analysis of a previous questionnaire distributed to 120 practitioners in the Gulf region, concluded that 78% had concerns about the difficulty in quantifying the benefits of green buildings and problems with the evaluation documentation process (Salama and Hana, 2010). It was also concluded that the construction industry in the UAE was witnessing a growing awareness of sustainability but the inconsistency of the responses reflected a blurred awareness of the key concepts of green building.

The Emirates Green Building Council (GBC) encourages the use of any recognized green building rating method as a means to creating a more sustainable built environment. There are several methods in the global market place as well as several methods commonly used in the United Arab Emirates (UAE). In the sections below a description of the commonly used methods is given together with a critique followed by the explanation of how an alternative assessment framework was developed, which was devised to be more straightforward to use and addressed the main needs expressed by professionals.

It is important to pursue development and integration of sustainability assessment at this period in history and some argue for intervention from governments to legislate for sustainable buildings and to create design and construction strategies to minimize the environmental impact of new building construction activity. In Kuwait, a survey indicated that 88% of respondents agreed that rules and legislation from government are required to enforce the concept of green buildings (Al Sanad, Gale, and Edwards, 2011). Another survey, concerned with evaluation of new residential building codes in the UAE, showed that using such codes could reduce the CO2 emissions of buildings by 50% (Radhi, 2010).

EXISTING ASSESSMENT METHODS

Assessment tools for environmental analysis of buildings and their surroundings come in many shapes and forms. Some address single issues such as energy use/carbon dioxide production or indoor air quality, whilst others incorporate a wide range of issues under an umbrella tool. The criticism that can be leveled at the latter when it results in a single figure outcome or single rating is that the overall rating compares dissimilar things. This criticism can be partly dealt with by using weighting systems between sub-categories that are agreed across issue boundaries and which can be periodically adjusted. Nevertheless it is the case that most countries have opted to use an overall assessment system as the notion of a single descriptor/evaluation has more public appeal. Over the years a large number of assessment systems have been developed in different countries. Some are prescriptive requiring answers to a large but defined set of questions; some are more flexible. The categorisation can also arise from whether the method is aimed at design features and operation (LEED, BREEAM) or whether dealing with life cycle assessment in great detail such as the German Deutchse Gesellschaft fur Nachhaltiges Bauen (DNGB), the Dutch EcoQuantum, or North American ATHENA. Methods also exist that are wider in scope and more dynamic, such as SBTool (developed by the IISBE organisation from the earlier GBTool). SBTool uses a toolkit approach from which users select relevant issues to suit their building type and location. The Living Building Challenge (LBC) which comprises seven performance categories: place, water, energy, health & happiness, materials, equity, and beauty, takes the approach to a different level by focusing on ‘imperatives’ which can be applied to a wide range of projects and which are undated in response to the market and current state of knowledge.

In this study a wide range of options were considered from which it was decided to focus on three examples of the design-led assessment, two of which have been widely used around the world and have established a place in the market. To these was added a more recently developed local GCC tool. A wide range of assessment methods and tools were examined for use in the study and three well-known options which could be applied were identified.

The reasons for choosing the three methods with their indicators for evaluation were: they are the most common methods in the Gulf region and are recommended by the UAE GBC; they had the ability to offer comparisons and benchmarking; they evaluated whole buildings and not only building parts; they provided a label and third party certification; there was a credible responsible organization behind the label; and they could be applied in different countries or were designed for cross-border application.

BREEAM Gulf 2008

BREEAM (the Building Research Establishment Environmental Assessment Method) was the first assessment system, launched in 1990, to offer an environmental label for buildings. BREEAM Systems are voluntary, consensus-based, and market-driven. Different schemes of BREEAM exist around the world and have been adapted to suit the regions in which they are to be used and to reflect differences in standard practice or cultures (Saunders, 2008). For international projects seeking evaluation under the BREEAM scheme, they should initially use BREEAM Bespoke International. This also allows an opportunity for the client to appoint a local consultant/expert to research the local codes and standards for the particular country/region. The Building Research Establishment uses this information to devise a set of final criteria to be used by the assessor to carry out the assessment on that particular building.

BREEAM Gulf was developed in collaboration with a variety of large organizations based in Qatar, Abu Dhabi and Dubai, with its objective to assist the construction industry in the region to achieve higher levels of sustainability and to recognize local context and issues (BREEAM, 2008).

LEED v.3 2009

LEED (Leadership in Energy and Environmental Design) is owned and administered by the US Green Building Council (USGBC). The method is flexible and can be applied to all building types: commercial, residential and entire neighborhood communities; and works throughout the building lifecycle: design and construction, operations and maintenance. LEED was identified by the Dubai authorities as a ‘tool’ to implement the region’s sustainability ambitions in a systematic manner, with the aim of an end-product that could be officially certified and therefore, internationally recognized. The Green Building Certification Institute (GBCI) was established in 2008 as a separately incorporated entity with the support of the U.S. Green Building Council for project registration and certification. LEED addresses several different project scopes for different building types; the latest version is version 4 which was released in late 2013; the version used in this analysis however was version 3 from 2009.

Pearl 2010

The Pearl Rating System was a key initiative of the Abu Dhabi Urban Planning Council (UPC) under the title Estidama (which means ‘sustainability’ in Arabic) and is a comprehensive rating system. Pearl was released early in April 2010 to provide a sustainability assessment program that aimed to be robust and tailored to the United Arab Emirates in terms of culture and climate. The system covers four pillars of sustainability: environmental, economic, cultural and social. The Pearl system aimed to address the sustainability of a given development throughout its lifecycle from design through construction to operation. The system provides design guidance and detailed requirements for rating a project’s potential performance (Estidama, 2010). It is however, like the others, a complex assessment to implement.

RESEARCH PROCESS

The aim of this research has been to develop a suitable sustainability assessment framework for office building relevant to the local context and priorities of the Gulf region. The research used ‘Mixed Methods Sequential Exploratory Design’ as a research methodology. The purpose of this exploratory sequential design was to develop and test a simple but reliable assessment framework and to generate design parameters. The first stage of the study was a qualitative exploration of theories regarding local context constraints and assessment method practices in the Gulf region. The second, quantitative stage followed-up on the findings from the qualitative stage for the purpose of examining the findings from multiple perspectives. Alternative sources and methods were used to compare, validate, and triangulate results and to examine processes/experiences along with outcomes. Comparative analysis data, case study and self-administered questionnaire were the main elements of the quantitative research.

The main task in the research was to choose and formulate the most appropriate ‘indicator set’, which considered the building's performance in relation to the local environment, culture and economy, as well as business goals. Furthermore, it was the intention to limit the number of indicators in the proposed framework to encourage take-up. Fernández-Sánchez and Rodríguez-López (2010) proposed a methodology used here, based on the identification of sustainability indicators by considering sustainability as opportunities for the project and on the establishment of indicators for measuring and controlling these opportunities. A framework would be essential for linking the vision and goals to the evaluation methodology and the indicators that are to be selected. The initial step was to choose the most appropriate criteria for the indicator set. Alwaer and Clements-Croome (2010) suggested four hierarchical categories of indicators to facilitate the selection process: *Pre-requisite* (Mandatory) indicators which are compliant with standards, regulations and quantified minimum targets; *Desired* indicators: ideal targets for building performance beyond the minimum required by regulations and codes of practice, to include the users vision; *Inspiring indicators*: goals and visions set by client: referring to long term mission and values; *Non-active indicators* or *non- applicable indicators* (the scope of this research project does not require these, and are thus ignored in the analysis). They should also be:

- Representative: Assist in informing choice in design decisions.
- Reasonably simple: Be usable by anyone, including professional designers and lay users with a simple and clear interface.
- Sensitive to change: Be flexible, multipurpose and generic in nature, and useable on many different types of buildings. Therefore enduring and persisting.
- Time resilient: Reflect specific aspects that could have impacts on sustainable buildings for current and future developments.
- Quantitative: Be quantifiable and scientifically valid (quantitative aspects or qualitative converted to quantitative).
- Accurate: Accurately/objectively measure progress towards sustainable development goals.
- Cost-Effective: Be cost effective but give value.
- Accessible: Data accessibility should be made easy and not constrain the process.

A methodology of five design sequential stages was employed: Stage 1 - Critical selection of aspects and indicators; Stage 2 - Structuring of the framework and refinement of selected indicators through comparative review of three existing sustainability assessment methods; Stage 3 - Structuring of the framework and refinement of selected indicators through a case study building study and comparative analysis; Stage 4 - Validation of the framework and indicators through questionnaire survey to local sustainable buildings industry professional; Stage 5 - Results analysis.

Arising from the evaluation, it was clear that all three methods required a high level of professionalism in sustainable design knowledge to be effectively used. The time and cost associated with this specialized knowledge is an important consideration. Moreover, the time required for documentation production is long and even though online submission is possible, the response time from the organisations is relatively lengthy. Typically four to six months is required for complete processing the applications; local experts' opinions suggest that it is usually longer, which also hinders acceptance in the marketplace. Also found as a result of the questionnaire was that the culture of the building industry relied on quick decisions. Credits within the assessment schemes that required substantial effort to be documented and which used external expertise, resulted in extra cost and time for the applicant, and this was one of the major criticisms. The survey also revealed that cost of assessment and documentation was a difficulty as was lack of awareness of the benefits. It was also found that expanding the range of issues in the methods, would also act as a disincentive to use.

The analysis showed that there was a good degree of commonality in approach of the three methods. The compatibility ratio among all the credits of the methods is high when related to the full data set: 65.2% for BREEEAM Gulf and 77.27% for LEED. And in spite of the expanded structure of Pearl in covering more phases of the life cycle, cultural themes of sustainability, natural systems and compliance with the Abu Dhabi plan 2030; the method showed 55.86% compatibility. This gives confidence in being able to define a reduced set of key indicators in a new framework.

DETAILED DEVELOPMENT OF FRAMEWORK

Thirty LEED certified projects in UAE, representing 90% of all LEED certified projects in the Gulf region up to August 2012, were analysed and evaluated and compared to BREEAM and Pearl at the same time. The projects were mostly offices, offices combined with industrial premises, and hotels; ratings achieved fell into the following categories: platinum 10%; gold 46.6%; silver 36.7%; and certified 6.7%. This thirty-project analysis provided a basis for understanding which indicators would be of most value from the wide range to be found if every credit from all three systems were combined.

In order to limit the number of indicators in the proposed new framework to the most relevant and significant, a prioritization process was required. Areas of assessment that were common to all evaluation processes were immediately designated for inclusion in the proposed framework. For the remainder, an analysis was made to determine what priorities would be selected if considered relevant to the following: the most severe local problems; local governmental and stakeholder objectives; mandatory rules and regulations of authorities; Gulf region environmental practices; and regional priorities and synergistic strategies. The sections below indicate in more detail the activities carried out.

Theoretical comparison: To characterize the essence of the three methods, the evaluative framework for environmental management approaches developed by Baumann and Cowell (1999) was adopted to structure the frameworks of the three methods. The purpose of using a framework is to give a better understanding of the context structure with recognized terminology and methodology.

Review of criteria addressed by area-context priorities: To allow review information for each of the three applicable assessment methods, by using the local context priorities drivers for sustainable design, seven criteria were identified: applicability, development, usability, system maturity, technical content, measurability & verification and communicability (Fowler and Rauch, 2006).

Comparison of methods standards and regulations: This aspect investigated and compared each of the three methods to show the level of compliance with standards and regulations on international, regional and local levels.

Comparison of methods impact categories/indicators: To examine the degree of synchronization and the potential for harmonization; since the same elements sometimes appear in different categories in the three methods a direct credit points allocation comparison can be difficult if not impossible (Smith et al, 2006). Accordingly, to allow for more objective comparison and to minimize internal systematic biases associated with the benchmarking of a comparative study, a system of harmonization was employed in which some aspects were reclassified. Figure 1 illustrates the outcomes following the harmonization process by comparing the allocation of weighting from the three methods across ten categories into which the indicators were allocated.

Information and findings from the theoretical and synchronized comparison revealed that the three methods were important in stimulating the market for sustainable building in the Gulf region and that the existence of more than one method could create competitive practices that might enhance the industry. None of methods were fully compatible with regional requirements, particularly in addressing criteria of some environmental issues, or in providing practical applicability to deal with regional contextual issues.

The detailed comparisons were then informed by analysis of their application to a case study building: one for which detailed design information was available and which had already achieved a high classification in LEED. The total number of sustainability certified new buildings up to July 2012 was thirty; two of them having LEED platinum certifications; the case study building was chosen to be one of these: the ESAB Middle East FZE office building. Space does not permit a detailed description of the case study analysis; however it enabled the choice of indicators to be substantiated.

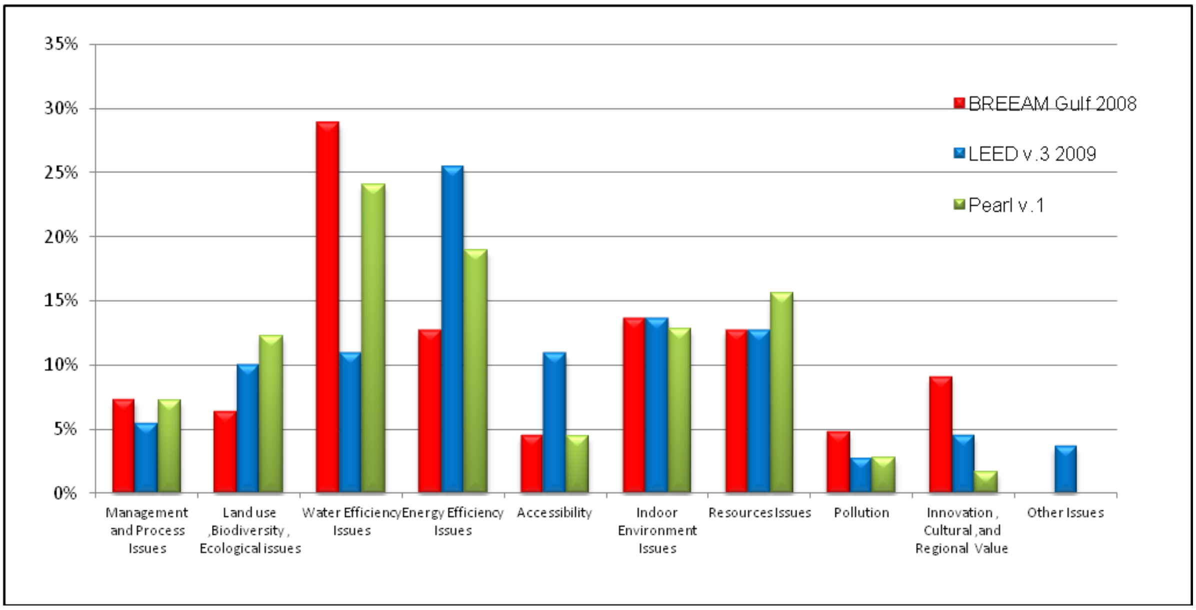

Figure 1 Comparisons of the synchronised and harmonized credit weightings for BREEAM, LEED and Pearl according to credit category.

GULF-REGION OFFICE-BUILDING SUSTAINABILITY ASSESSMENT FRAMEWORK

Arising from the various analyses, 24 indicators were initially chosen grouped under 5 main categories: Site Location Biodiversity & Accessibility; Energy; Water; Occupant Well-being; and Resources and Waste. The allocation of indicators was as follows:

Site location, biodiversity and accessibility (7 indicators): Site ecology; Construction pollution; Public Transport accessibility; Travel planning; Cycle facilities; Electric cars and car-pooling facilities; and Heat island effects on roof and other surfaces

Energy (5 indicators): Primary energy consumption for building operation; Commissioning; Energy monitoring; Ozone depletion/enhanced refrigerant management; and On-site power generation

Water (4 indicators): Interior water consumption; Exterior water consumption; Waste water technologies; Water consumption monitoring

Occupant Well-being (4 indicators): Indoor air quality; Thermal comfort; Smoking; and Emissions from materials.

Resources and Waste (4 indicators): Waste storage/recycling; Recycled construction materials; Locally sourced materials; and Construction site waste management.

SURVEY OF BUILDING PROFESSIONALS AND SELECTION OF INDICATORS

In order to validate the approach being used a survey of building professionals' attitudes was carried out using a questionnaire based on the assessment framework. In total 91 responses were received and 87 of those were deemed to be valid and answered all questions. Responses to key questions are shown in Table 1. The survey also asked participants to rank the importance of the proposed indicators on a scale of 1 to 4. It was also found 87% of industry professionals agreed that the proposed framework would be effective in enhancing performance of office buildings in the Gulf region.

One of the most important aspects of the survey was to confirm or exclude indicators and to check for availability of appropriate benchmarks or indicator-specific analytical tools in order that the value of the indicator could be calculated. A cut-off value of 3.0 was chosen as signifying the professionals' acceptance of the indicator. Table 2 shows the summary results and that four indicators were excluded. The determination of the availability of benchmarking/analysis tools was made easier by the previous comprehensive assessment of available methods for the Gulf Region. In two cases specific additional information to that normally used would be needed to enable the calculation, and in two further cases it was determined that a slightly modified version of the benchmark analysis would be required.

Table 1. Responses from Building Professionals to key questions about sustainability

Response to question	Sustainable Development is a very important concept and principle for the Gulf region countries	Sustainability assessment is an important issue for office building development in the Gulf region	Current design approaches adopted within the building industry in Gulf region countries are creating sustainability problems
Strongly agree	59 (67.9%)	50 (57.5%)	49 (56.4%)
Agree	25 (28.7%)	34 (39.1%)	32 (36.8%)
Disagree	1 (1.1%)	3 (3.4%)	4 (4.6%)
Strongly disagree	2 (2.3%)	0 (0%)	1 (1.1%)
No response	0 (0%)	0 (0%)	1 (1.1%)

Table 2. Gulf-region Office-building Sustainability Assessment Framework: confirmation of indicators to be used from survey and benchmarks (*= further information needed for benchmark use; **=modified benchmark)

Indicator	Rank weighting (out of 4)	Confirmed as included	Benchmark availability
Site ecology	3.91	Confirmed	Confirmed*
Construction pollution	3.67	Confirmed	Confirmed
Public transport access	3.55	Confirmed	Confirmed
Travel planning	3.40	Confirmed	Confirmed
Cycle facilities	2.93	Not confirmed	Excluded
Electric cars	2.84	Not confirmed	Excluded
Heat island effects	2.84	Not confirmed	Excluded
Minimise primary energy	3.83	Confirmed	Confirmed**
Commissioning	3.77	Confirmed	Confirmed
Energy monitoring	3.55	Confirmed	Confirmed
Ozone depl/refrigerants	3.54	Confirmed	Confirmed
On-site power generation	3.37	Confirmed	Confirmed**
Interior water use	3.94	Confirmed	Confirmed
Exterior water use	3.74	Confirmed	Confirmed
Waste water technologies	3.45	Confirmed	Confirmed
Water use monitoring	3.36	Confirmed	Confirmed
Indoor air quality	3.78	Confirmed	Confirmed
Thermal comfort	3.76	Confirmed	Confirmed
Smoking	3.71	Confirmed	Confirmed*
Emissions from materials	3.58	Confirmed	Confirmed
Waste storage/recycling	3.70	Confirmed	Confirmed
Recycled const. materials	3.43	Confirmed	Confirmed
Locally sourced materials	3.46	Confirmed	Confirmed
Const. site management	2.92	Not confirmed	Excluded

A further question concerned the respondents' perceptions regarding impact categories that affect sustainable design of office buildings. Energy and water at 97.7% and 93.4% respectively were the most frequently cited issues. Other categories scored as follows: occupant well-being 73.6%; site location and biodiversity 70.1%; resources and wastes 56.3%; and operation and maintenance 49.4%.

The impact of the survey results was to confirm the approach and scope of the new assessment method described in this paper and to encourage further research and development.

CONCLUSIONS

This paper has presented the key features of a research project designed to generate a new and more easily applied sustainability assessment framework suited to the circumstances of the Gulf Region. The Framework is well-founded being derived from a detailed analysis of available international methods but enhanced by focusing on the key parameters that can be applied efficiently in the Gulf Region. Further analysis and evaluation is required to determine the most effective means to bring the system to the market-place and to assess any potential limitations of the Framework in practice. The data gathered from the professionals and from the study of the previously assessed thirty projects will permit the next stage – that of allocating a more sophisticated and justified weighting to each indicator, to be carried out.

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Session 5E : Material technology

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Evaluating the Performance of Naturally Ventilated Brick and Lime Domes and Vaults in Warm-humid Climate in South India

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ABSTRACT

India has a rich tradition of passive architectural design practice. There has been, however, little effort to study these design strategies to evaluate their effectiveness. This study analyses the climate responsiveness and thermal performance of domes and vaults in brick masonry.

The study compares the performance of hemispherical domes and segmental vaults in a residence-office building for indoor conditions measured on hourly basis for one year. The study gives the necessary quantifiable performance of domes and vaults constructed using low-cost, local materials as an effective energy efficient design strategy that may be easily adopted as a practice.

INTRODUCTION

Vaults and domes appeared in Auroville in 1982 as an answer to the cement shortage after the oil crisis of 1979. Imported cement from Vietnam and South Korea was being sold in the black market in India at a high price. The labor intensive and high thermal mass construction of domes and vaults in local country fired bricks with lime mortar seemed to be the ideal alternative to RCC roofs.

They can be a good example in today's context of high energy intensive construction techniques. While addressing the increasing demand of housing in India with the use of natural materials, innovative techniques and engagement of local craftsmen as a cost effective, culturally, socially and economically sustainable means; they also provide a continuum of traditional knowledge and employment generation in the region.

An example of a residence-cum-office complex using these techniques was chosen for this study. From the two residences, we have concentrated on the right side of the complex (refer photo – fig 1), which consists of three domes and three vaults, since two of these domes provided us an opportunity to study different ventilation systems – one with an air vent and one with aluminium wind extractor *(Dome 2; Fig 4).*

Figure 1 Mukuduvidu Complex. Southern facade, 1992

CONTEXT AND CLIMATE

Auroville context (warm-humid climatic zone of India):

Latitude:12° N | Longitude: 80° E | Altitude: +60 MSL Winters (Nov – Feb) : 21 °C to 32°C Summers (April – July) : 28°C to 41°C	Daily radiation received: 4 to 7 kWh/m (peak – 1 kW/m² at noon) Annual average rainfall : 1,200 mm North-east monsoon (Oct – Dec) - approx 60% of the annual rainfall South-west monsoon (June – Sept) - approx 20% of the annual rainfall

Alternating land and sea breeze provide reprieve from the hot and humid climate. Relative humidity varies from 60% to 90% throughout the year and wind velocity varies from 0 to 8 m/s with 1.4 m/s annual average (AV weather station data / CBERD project).

Case study. Mukuduvidu Complex. Fact File :

Year:	1990 - 1992
Usable area:	96m^2(ground floor); 48 m^2(first floor); Total: 144 m^2 (this represents the part under study only)
Architects	Poppo Pingel and Mona Doctor-Pingel
Passive Strategies	North-south orientation | thermal mass – 0.22 m load bearing low fired country brick with lime mortar and plaster | 1.2 m overhangs in the south and north | wind exhausts for domes, high ceiling with vault structure to allow for ventilation under the roof | maximum large openings on the south, less large on the north side (rain direction, sun in the summer) with minimum opening of the east and west side | domes are covered with reflective white broken china mosaic | Extensive landscaping with large trees on the west and north, water bodies and Zen sand garden to the south.
Construction methodology:	Up to 4 m spans for vaults and 5 m diameter for domes are economical from structural and functional point of view with this construction method. Vaults were constructed by a wooden sliding shutter of 1 m width. The flat roof achieved by a vaulted roof also allows a terrace for drying and sleeping during the hot summers. Local unskilled labor can be easily trained in the simple masonry required for domes and vaults. A single casuarina pole fixed in the center with a rotating arm acted as a guide to create a hemispherical dome and within a week, the roof was created (Fig. 7.1). All construction work was done manually.
Principles of Baubiologie Employed	Baubiologie (Building Biology) - the study of the impact of built environment on the health of the people and the application of this knowledge to the construction of healthy homes and workplaces – was applied in this building | Concerns of electro-magnetic fields taken care of by a judicious design of electrical layout | Use of natural materials | Bio concrete for the RCC beams, specifically made with hand-cut limestone chips as aggregate | Waterproofing of domes and vaults done without use of chemicals | Natural water-bodies that are self maintaining | All plants are indigenous requiring minimum watering | Waste water is treated and feeds fruit trees | Solar PV with battery, solar water heater, solar cooker for cooking

RESEARCH OBJECTIVES

1. Effectiveness of brick masonry hemispherical domes (internal dia 4.8 m) and segmental vaults (rise 0.55 m and 3 m span) to provide thermal comfort as per adaptive thermal comfort model of ASHRAE 55 across the year as a naturally ventilated building without using any electrical system such as fan to generate air velocity.
2. Identify the time lag in thermal transmission occurring through different walls and roof.
3. Efficiency of the wind extractors installed in a ventilated opening at the top of the dome.
4. Establish the WWR for hemispherical dome space and study it vis-à-vis its adequacy of sufficient air movement.

APPROACH

Within the CBERD (US-India Center for Building Energy Research and Development) project, under the umbrella of Auroville Center for Scientific Research (AV CSR) we are monitoring this building since September 2013 with hourly readings from 10 loggers and 15 sensors placed within the two domes on the first floor and the space on the ground floor formed by exposed brick vaults. The domes have a slightly different construction type: one is with squinches on a square base and another is with precast concrete circular beams also on a square base from where the dome springs. The two domes also have different ventilation system for hot air evacuation (Ref Fig 5 & 6).

Mona Doctor-Pingel has an independent architectural practice, Studio Naqshbandi, and is a team member of CBERD project. Rajan Rawal is Director, Center for Advanced Research in Building Science and Energy, CEPT University. Anna Bakhlina, is an architect, Studio Naqshbandi. Vijai Krishnaraj is an instrumentation engineer, CSR, Philippe Bourdon is a student in construction and energy engineering, ESIROI, Reunion Island

Logic of loggers placement

Surface temperature sensors are placed inside and outside the dome surfaces (at different heights) within the dome. Each of the sensors is covered with a white thermocol strip (25 mm x 50 mm x 5mm, Figure 7.5) to protect the sensor and to enable easy adhesion to the surface. One free hanging logger is placed inside each dome and the vault to measure air temperature and RH in the rooms (approximately 1.50 m above the ground, on the height relative to occupants use). There is a logger installed in a thermocol box (adaptation of the Stevenson screen) outside the residence for ambient temperature measurements. (For the type of loggers used and location refer the table and illustration – Fig. 2, 3, 4).

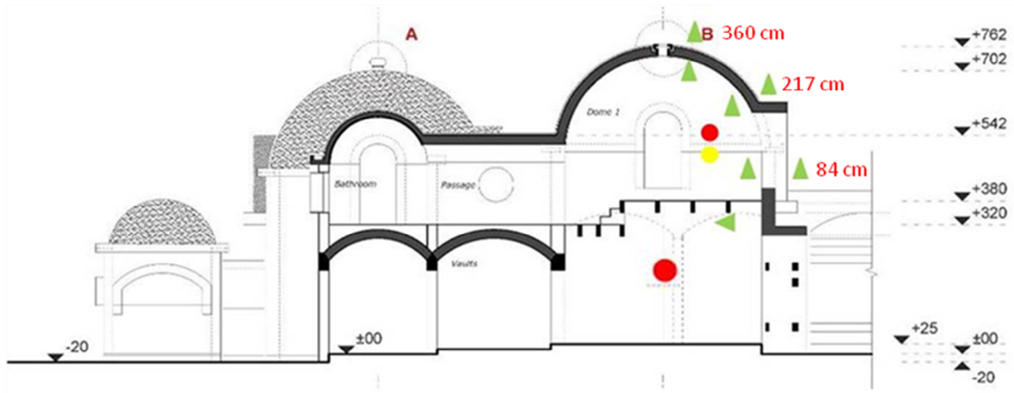


Figure 2 Section A-A' through **Dome 1** with placed data loggers and surf temp sensors placement (color code Figure 4)

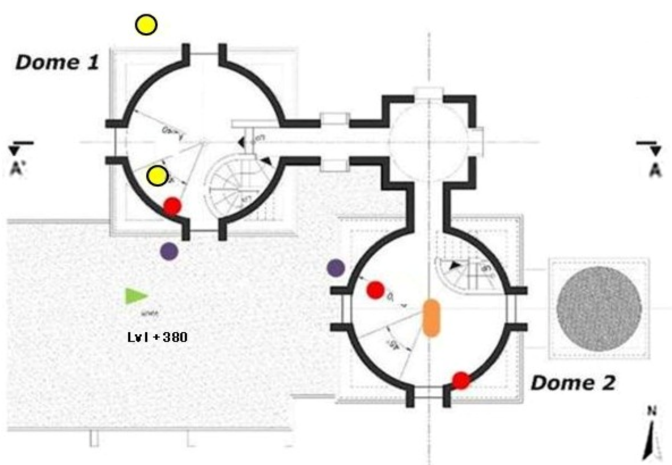


Figure 3 First floor plan with loggers placement.

	ONSET loggers			
	logger type	measurments	№ of loggers	accuracy :
	U12-012	temp, RH,Lux	2	T : ±0.35º C From (0 to 50 º C) RH: ± 2.5% (from 10 to 90 %)
	U12-013	temp, RH,	4	T : ±0.35º C From (0 to 50 º C) RH : ± 2.5% (from 10 to 90 %) External Input Channels : ± 2 mV ± 2.5% of absolute reading
	U12-006	-	2	± 2 mV ± 2.5% of absolute reading ± 2 mV ± 1% of reading for logger-powered sensors
	UX100-011	temp, RH,	2	T : ±0.21°C from 0° to 50°C RH : ±2.5% from 10% to 90% typical to a maximum of ±3.5% including hysteresis
	ONSET sensors			
	TMC6-HE 6' (6 ft) TMC20-HD (20 ft)	surf temp (thermistors)	14	±0.25°C from 0° to 50°C
	T-DCI-F900-L-O	air-velocity (single drection,hotwire)	1	+/-0.05 m/s or 1% full-scale

Figure 4 List of loggers and sensors.

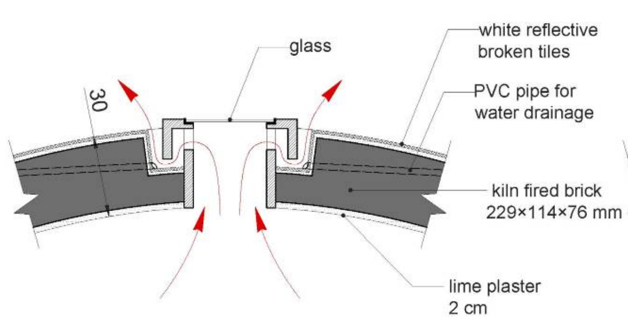


Figure 5 Detail B. Dome 1. Air vent.

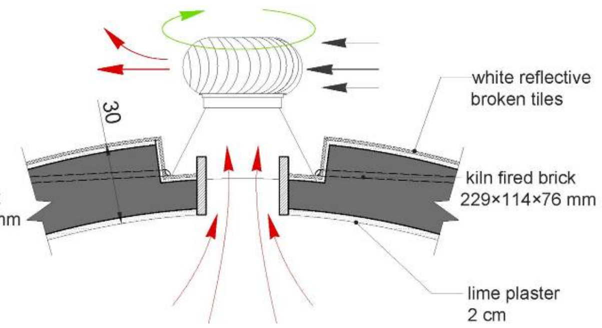


Figure 6 Detail A. Dome 2. Air vent with wind extractor.

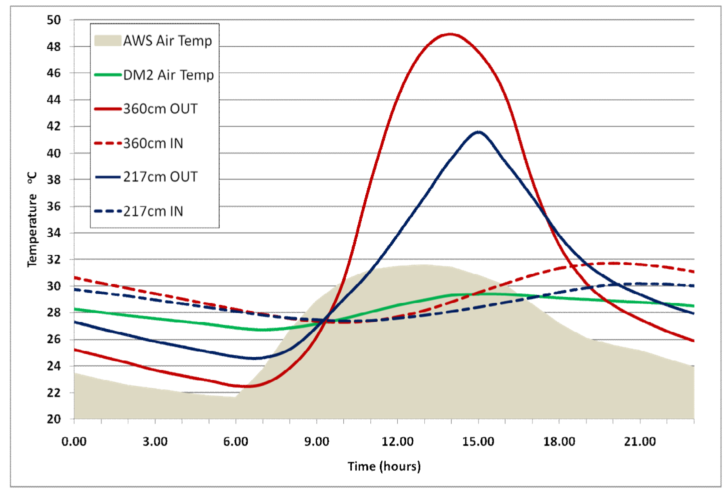
Additionally hand held readings are taken every three weeks, measuring air, globe and surface temperatures, air-velocity and humidity in every room under study as well as checking for any specifics that could not be taken by continual data logging. Any changes or abnormalities are recorded meticulously.

Surface temperature sensors are placed on ceiling and rooftop both for the vault and the domes. Weather data is obtained from an Automatic Weather Station (AWS) set up by the Indian space research organization at Auroville.

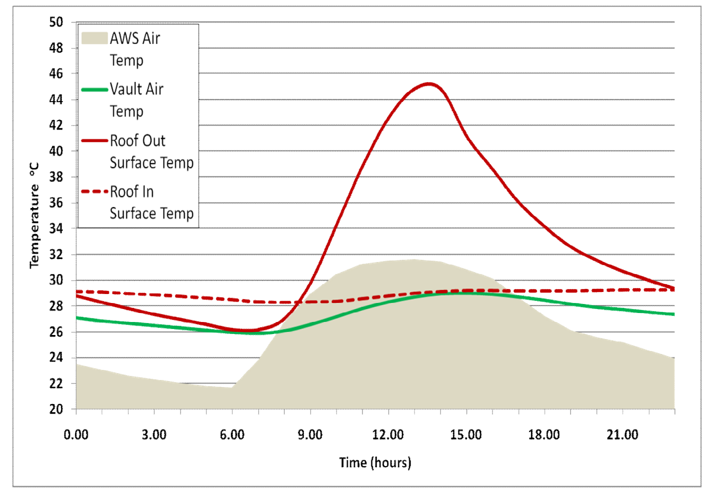
Figure 7 From the left: **1 -** Dome with rotating arm under construction; **2** – Air vent opening detail on the top of the dome; **3** – Dome 2: Air vent with wind extractor; **4-** Air-velocity sensor fixed in the Dome 2; **5 –** Fixed surface temp sensor on the vault covered with white thermocol strip

OUTCOMES

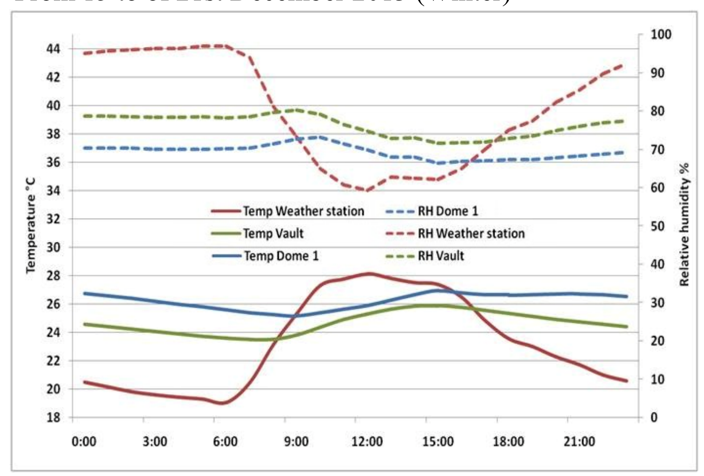
Graph 1. Hourly values of mean surface temperature for Dome 2 - IN vs. OUT March 2014



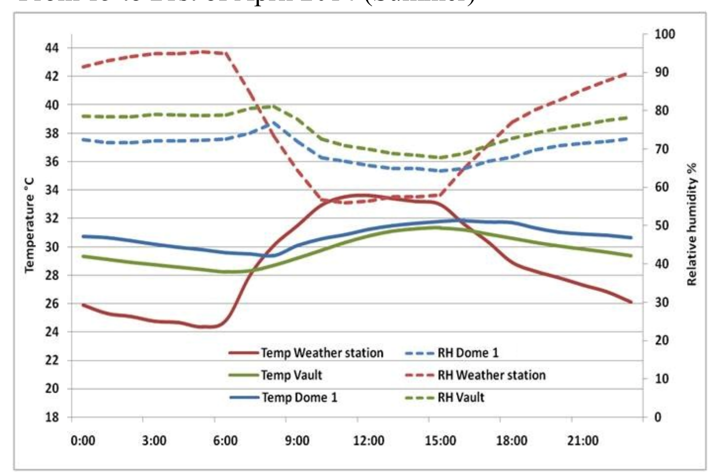
Graph 2. Hourly values of mean surface Temperature for Vault - IN vs. OUT March 2014



Graph 3. Hourly values of mean Relative Humidity and Ambient Temperature of Dome 1 vs. Vault From 15 to of 21st December 2013 (Winter)



Graph 4. Hourly values of mean Relative Humidity and Ambient Temperature of Dome 1 vs. Vault From 15 to 21st of April 2014 (Summer)

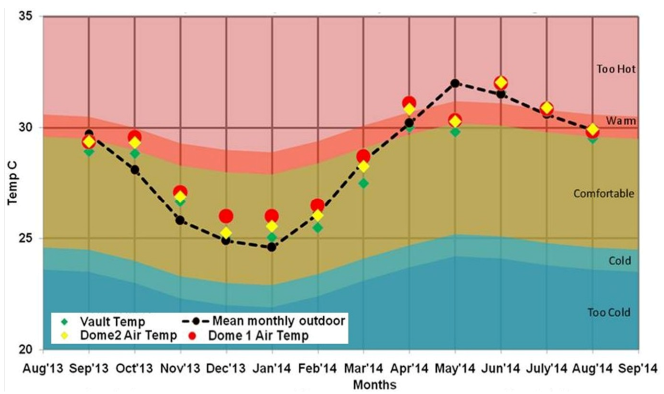


Graph 1 indicates that the outside surface temperatures are increasing towards the top of the dome, due to the increasing sun exposure, the same trend is reported for the inner surface with a 6 hours thermal lag (from outer to inner surface).

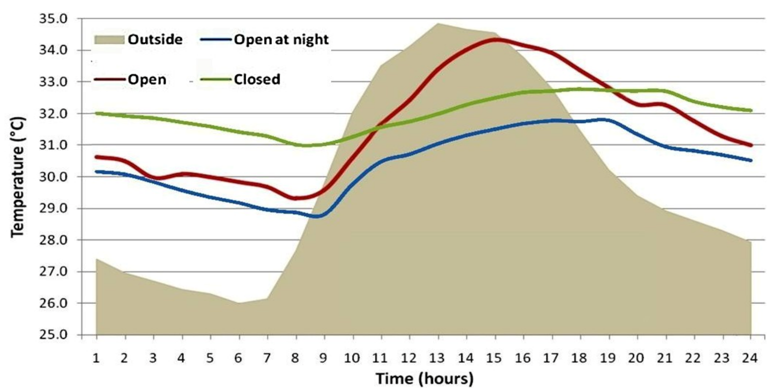
Graph 2 shows the performance of the vault in the same condition and through the same period of time as Graph 1. The time lag is more significant than the dome. The ceiling thermal lag is 8 hours from outer to inner surface. Ceiling surface temperature remains relatively stable thanks to high thermal mass and cross ventilation occurring in the vault.

Graph 3 and Graph 4 shows the comparison of the indoor air between the dome and vault looking at one week data in December (winter) and April (summer). In summer, the air temperature time lag is 3 hours for the vault and 4 hours for the dome. In winter, time lags dropped to 2 and 3 hours. Winter sees lower time lags but the same trend remains, the vault has the shortest air time lag which is synonymous to a more efficient cross ventilation.

Graph 5. Values of mean temperature in Dome 1, Dome 2 and Vault from Sep 2013 till Aug 2014 with Adaptive comfort zones (CARBSE), for Naturally Ventilated Buildings, *(13 ^{0}N, Chennai)*



Graph 6. Dome 1 air temperature with 3 different opening scenarios (weekly mean in April-May 2014): Windows closed throughout day & night; Windows open throughout day & night; Windows open at night and closed during the day



Graph 5: Overlapping the mean monthly temperatures of the building with the adaptive thermal comfort zones elaborated by CARBSE for Chennai, we can observe that the vault remains within the comfort range from September to May, whereas domes are within the comfort range from September to April (without any electrical ventilation system). Dome 2 is slightly cooler than the Dome 1, the major difference coming from the wind extractor proving that wind extractor helps to reduce the indoor temperature by increasing hot air extraction even when windows are closed. We can conclude that vaulted space shows better thermal performance.

Graph 6 compares the air temperature for three windows opening scenarios in Dome 1 and clearly indicates that the strategy to close the windows during the day to keep the fresh air and opening at night to cool down shows the best results. Detailed analysis of our data shows that windows open at day (09-18hrs) increases the indoor air temperature by 2°C more than when they are closed. Also windows open at night (18-09 hrs) allows an extra cooling of 1.2 °C than when they are closed.

Air Velocity measurement in Dome 2: The maximum and minimum air velocity recorded at the wind extractor is 1.54 m/s and 0.11 m/s respectively. The average is 0.57 m/s. The hourly mean values show that the air velocity increases at night time when land breeze prevails. More data and studies need to be undertaken with sophisticated instruments on the air movement in the room especially for the cross ventilation.

Surface to Volume Ratio and WWR study.

The vault has large overhangs on the south and north (1.2 m) and walls that are shaded / shared on the east and west. The domes have smaller overhangs on openings only (0.6 m) and the dome surface gets heated by direct sun radiation throughout the day, while the vault get alternately heated on the East then on the West side, not both at the same time. This difference has a repercussion on heat transmission and storage in the walls.

Table 1. Surface, volume and WWR calculation of the room with spherical dome and comparison with an equivalent vault-flat roof room interims of area & volume.

	Existing Dome	Equivalent Vault
Floor surface area	23 m²	23 m²
Internal volume	60.2 m²	60.2 m²
Internal height	3.6 m	2.61 m
Exterior surface area	79.5 m²	88.8 m²
Exterior wall surface area *	69.56 m²	60.71 m²
Surface area of openings	6.71 m²	32 m²
Window to Wall Ratio	**9.6%**	**36%**

* Exterior semi-spherical dome surface is counted as a wall surface

Comparing the WWR for vault and dome shows that the total area of opening is much less in the dome, mainly due to structural constraints. For the warm humid zone this leads to less possibility for ventilation and air movement.

CONCLUSIONS

- Thermal comfort can be achieved in a naturally ventilated building under a warm and humid climate using passive strategies. The overall performance of vault is more satisfactory than the dome in this case study due to its larger openings enhancing cross ventilation and lesser solar heat transmission.
- The thermal mass of the domes and vaults ensures a time lag of 2 - 4 hours for the air temperature. Domes' being less than the vault.
- Temperature on the surface of the dome increases towards the top.
- Ventilation at the center of the dome is important. The installation of the aluminum wind extractor on the top of the dome fares better than the air vent design as it increase hot air dissipation.
- The dome and vault are more comfortable in the winter than in summer months in warm humid climate. Other factors such as lifestyle habits and indoor air velocity would need to be considered.
- Air-velocity data for all the areas under study was not available. This would be important to take into account for naturally ventilated areas, especially without electrical ventilation systems.
- A comparison with modern RCC dwellings in the same climate can be undertaken in the next phase of research.
- Occupied buildings that are naturally ventilated are difficult to monitor, since behavior patterns and use of the building change with the outdoor conditions.

ACKNOWLEDGMENTS

We would like to express our gratitude to the following persons for guidance and support: Dr Brahmanand Mohanty, Dr Chamanlal Gupta, Tency Baetens, Poppo Pingel, CBERD team at CEPT University,

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Temperature Regulation and Thermal Energy Storage Potential of Phase Change Materials Layer Contained at the Back of a Building Integrated Photovoltaic Panel

Ahmed Hassan[1], Hamza Nouman[1], Ali Assi[2] & Brian Norton[3]

ABSTRACT

Photovoltaics (PV) deployed in high solar radiation high ambient temperature climate suffer huge loss in efficiency and degrade faster due to higher panel temperature. In order to overcome the temperature induced loss of power and life, s paraffin wax based solid-liquid phase change material (PCM) integrated at the back of PV is investigated in high temperature climate of UAE. The temperature drop on the PV panels due to inclusion of the PCM is recorded and compared to a reference panels without PCM. The associated voltage gain caused by temperature drop of PV due to PCM also recorded to evaluate the effectiveness of PCM in temperature regulation and electrical performance enhancement of PV. A temperature drop of 12 °C and and associated voltage gain of is observed which shows such systems are effective in even mild weather condition of a hot climate

INTRODUCTION

Silicon photovoltaics (PV) show a power drop above 25 °C with a temperature coefficient of up to -0.65 %-K-1 depending on type of the PV cell and the manufacturing technology [1]. The operating temperature reached by PV panels and associated power drop largely depends on the climate of the site. In Germany 50 % of the solar radiation incident on a PV panel is above 600 W/m2 while in Sudan this value reaches 80 % resulting different operating temperatures and associated power drop [2] urging a strong need for PV temperature regulation to maximize both panel lifetime and power output. Different passive and active heat removal techniques have been used to maintain PV at lower temperatures. Passive heat removal in free standing PV relies on the buoyancy driven air flow in a duct behind the PV [3]. Heat removal depends on ratio of length to internal diameter (L/D) of the duct [4] with the maximum heat removal obtainable at an L/D of 20 [5]. Passive heat removal in building integrated photovoltaics (BIPV) relies on buoyant circulation of air in an opening or air channel, instead of a duct, behind the PV [6] Active cooling of PV relies mostly on air or water flow on the front or back of the PV surface. Effect of air flow at different inlet velocities and air gaps on front side and back side of PV temperature was modelled and a maximum 34.2 °C temperature decrease was predicted at air inlet velocity of 1 ms-1 and front and back air gap of 20 mm [7] .Water flow on the front surface of a free standing PV has a decreased cell temperature of up to 22 °C along with decreasing reflection losses from PV surface yielding an 8-9 % increase in electrical power output [8]. Water flow on the back of a façade integrated PV has theoretically shown optimum electrical and thermal performance at a water flow rate of 0.05 kgs-1 for a particular system in the weather conditions of Hefei, China at insolations of 405 W-m-2 and 432 Wm-2 [9] .

Passive cooling of BIPV with solid-liquid PCMs were experimentally and numerically evaluated using a paraffin wax as PCM and an a rectangular aluminum container with internal dimension of (300

[1]United Arab Emirates University, United Arab Emirates, [2] Lebanese International University, Lebnese Republic,.& [3]Dublin Institute of Technology, Republic of Ireland, ,

mm x 132 mm x 40 mm) having selectively coated front surface to mimic a PV cell [10]. Temperature distributions on the front surface and inside the PCM were measured experimentally and predicted numerically with 2D and 3D finite volume heat transfer models which showed good agreement between experimental and numerical results [11,12]. Building on this work, Hasan et al., fabricated and characterised 4 different cell size PV-PCM systems to investigate performance of 5 different types of PCM to find out the optimum PCM and the PV-PCM system for this application. Two PCM, a eutectic mixture of capric-acid-palmitic acid, PCM1 and a salt hydrate CaCl2.6H2O, PCM2 were found promising in an aluminum based PV-PCM system [13]. In current work larger PV panels are integrated with in an aluminum based PV-PCM system containing PCM fitted internally with back to back vertical aluminum fins. The devised system is deployed outdoors in UAE climate during a mild season to observe the effectiveness of such PV-PCM systems.

METHODOLOGY

EXPERIMENTAL SETUP

Two 30W polycrystalline EVA encapsulated PV panels with dimensions of 500 mm x 400mm (PTL-Solar) were used in the experiments where one served as a reference and the other contained PCM. The calibrated t-type copper-constantan thermocouples with a measurement error of ±0.2 °C were installed on all and a National Instruments Compact- Rio data acquisition system was used to record the weather data on site for solar radiation intensity, wind speed and ambient temperature shown in figure 1. Rectangular PCM containers of internal dimensions 480 mm x 380 mm x 50 mm were fabricated from a 5 mm thickness aluminum alloy (1050A) and fitted with straight vertical back to back fins of the same alloy with 60 mm horizontal spacing. A 1 mm thin layer of silicon based glue was applied at the interface of the PV panel and the PCM container and kept under pressure for two days until the glue settled and a strong bond was realized between the aluminum container and the PV panel. The reference PV and PV-PCM were installed at the latitude angle in Al Ain, UAE between 23/03/2014 and 02/04/2014. The data acquisition measured temperatures on front and back surface for the reference PV and on front and back surface and in the middle of the PCM slab contained at PV back for the PV-PCM system. The open circuit voltage and short circuit currents were also measured for both the reference PV and PV-PCM system.

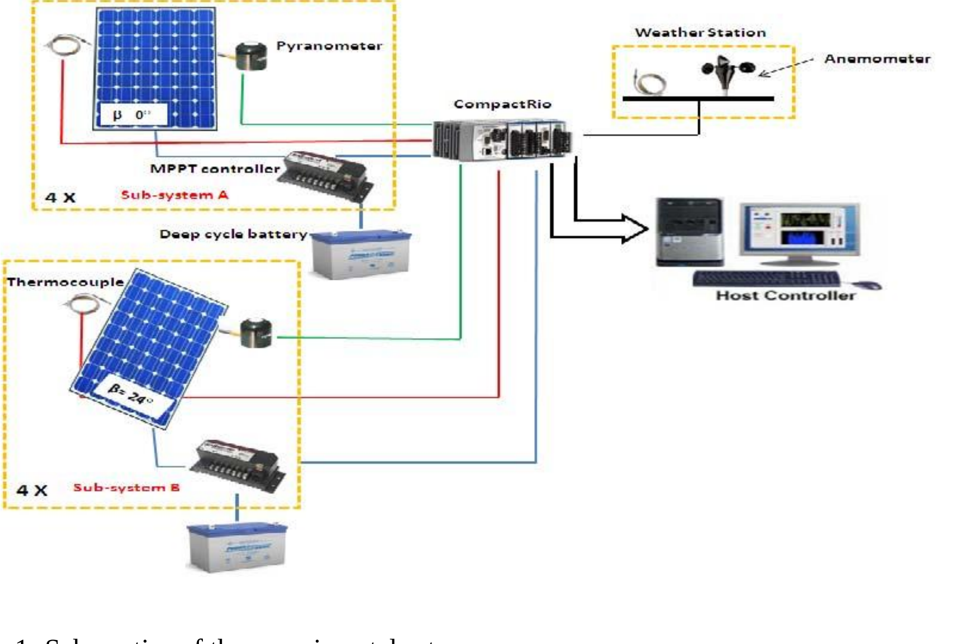

Figure 1- Schematics of the experimental setup

DATA ACQUISITION

Data acquisition system was built to record readings of the panel's voltage, current, temperature, and solar insolation. Besides, the site ambient temperature and wind speed were included in the data-logging architecture. CompactRIO 9073 was used as a real time data-logging device, while the data can be remotely monitored on a LabVIEW interface program. The developed LabVIEW program stores the PV panels' electrical and environmental variables during the daily sun hours. The data acquisition setup consists of the following components:

-CompactRIO 9073 : a reconfigurable real time controller and data acquisition chassis. The used model comprises 8 slots for I/O modules, 2 M gate embedded FPGA core, and a 266 MHz real time controller.

-NI 9227 : 4 channel differential analog current input module with nominal current rating of 5 A and maximum rating of 14 A. Two NI 9227 modules were used in this project, since 8 current measurements are required to be stored from the 8 PV panels.

-NI 9229: 4 channel differential analog voltage input module with maximum voltage range of -60 to 60 V. Two NI 9229 modules were used in this project to carry out 8 voltage measurements for the 8 PV panels.

-NI 9205: 32 single-ended channels or 16 differential channels analog voltage input module with maximum voltage range of -10 to 10 V. One NI 9205 module was used in this project, where 9 input ports were deployed to read measurements from weather sensors (8 pyranometers & 1 anemometer).

-NI 9213: 16 channel thermocouple input module. Only one module was used in this project, since only 9 channels were required, 8 to measure the 8 PV panels temperature and 1 was dedicated to measure the ambient temperature.

-Ethernet cable: Category 5 cable to establish the network between the host computer and the real time target (CompactRIO).

-NI LabVIEW development software: this includes the standard LabVIEW modules, the LabVIEW FPGA Module, the LabVIEW Real-Time Module, and the NI-RIO driver.

First, the NI CompactRIO system was assembled by installing the NI analog input modules, connecting the system to the host PC via an Ethernet cable, and powering up the device with its corresponding DC power supply. Then the network setting was configured to establish a communication between the CompactRIO and the host computer. Finally, an FPGA program was built on the LabVIEW development software and then stored in the real-time target. A host VI was built along with the FPGA VI to monitor the captured signals and represent them in plots and indicators.

RESULTS AND DISCUSSION

Figure 2, 3 and 4 shows the solar radiation intensity, ambient temperature and wind speed for the duration of experiment. Figure 2 shows that the day time peak ambient temperature varied between 29 °C to 37 °C which is a mild temperature for UAE weather conditions offers a peak day time summer temperature of upto 50 °C. Figure 3 shows that the peak time wind speed varied between 7km/h to 23 km/h. Figure 4 shows that peak time solar radiation intensity varied between 480W/m$_2$ on a cloudy day to 1240 W/m$_2$ on a very clear day. This weather caused the PV panel to heat resulting peak time reference PV temperature between 45 °C to 58 °C owing to the cloudy and sky respectively shown in Figure 5. The inclusion of PCM into PV resulted in a drop in PV temperature which reduced peak time PV temperature down to between 44 °C and 47°C shown on cloudy and sunny day respectively shown in Figure 5. The cooling effect produced by the PCM contained at the back of PV resulted in a peak time temperature drop of 5 °C to 11 °C on cloudy and clear sky conditions respectively shown in Figure 6. The temperature drop shown in Figure 6 reduced PV temperature resulted a higher open circuit voltage on PV containing PCM compared to PV without PCM shown in Figure 6 and yielded a voltage improvement peaked at 1.3 volts to 1.7 volts. The results shown in figure 6 explain that the PCM demonstrated a temperature regulation effect which was lower early in the morning for every day and increased as the PV reference temperature increased. Temperature results plotted over several days (Figure 5) also show that the PV with PCM showed a consistently lower temperature than PV without PCM which explains that the PCM regenerated every night to produce cooling for the next day. It is important to note that the PCM showed lower temperature regulation earlier in the morning while the reference PV panel temperature is below 40 °C, above this temperature during noon time, PCM showed higher temperature regulation. Figure 5 shows that the PCM achieved temperature regulation ranging from 8 °C in the modest temperature day compared to 11 °C on the hot day. It also points out that the PCM is expected to achieve higher temperature regulation in the higher temperature peak summer days which will be tested in coming months. From Figure 5 and Figure 6 it can be observed that the decreased temperature on the PV panel yielded an increase in PV voltage to enhance electrical power output from the PV.

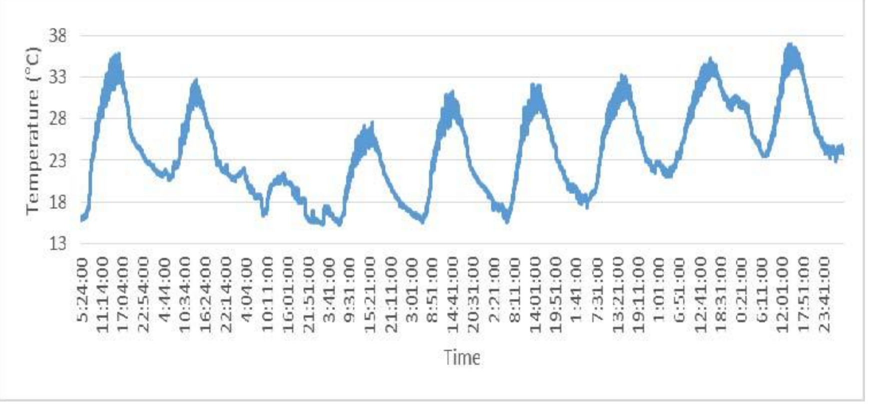

Figure 2: Ambient Temperature measured in Al Ain UAE, between 23/03/2014 and 02/04/2014

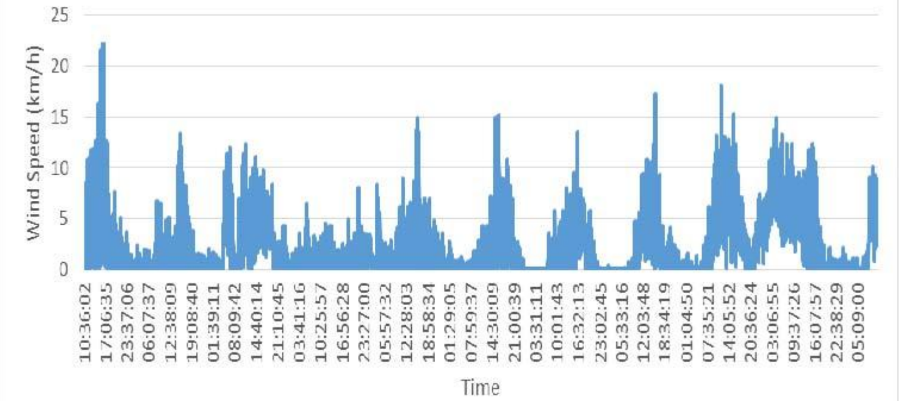

Figure 3: Wind speed measured in Al Ain UAE, between 23/03/2014 and 02/04/2014

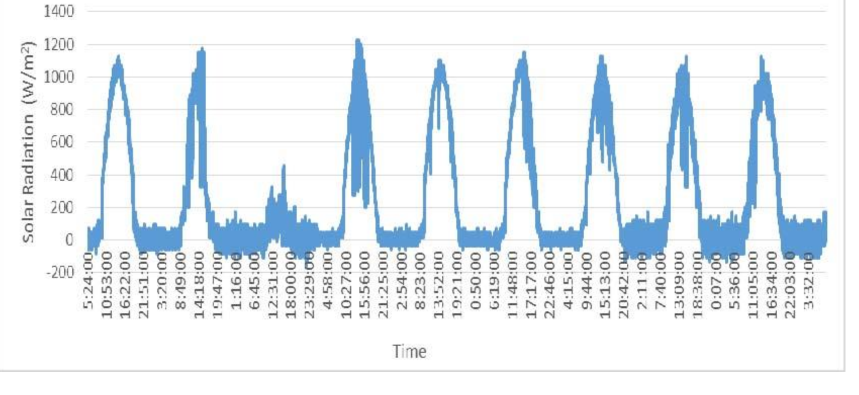

Figure 4: Solar radiation measured in Al Ain UAE, between 23/03/2014 till 02/04/2014.

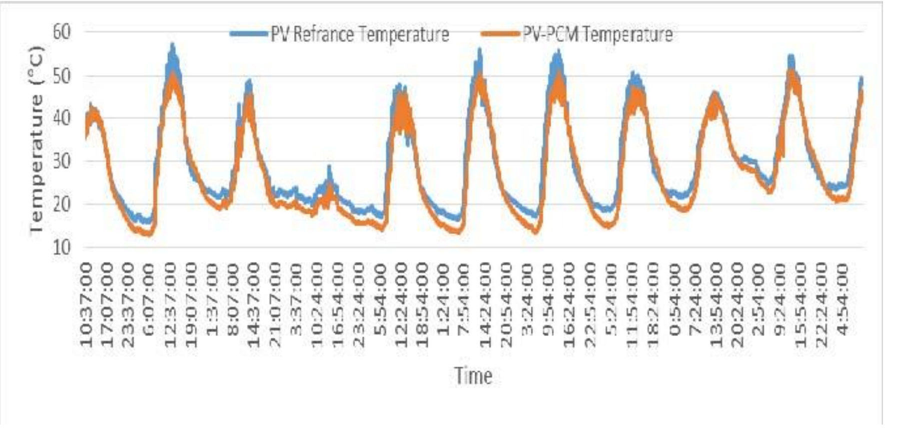

Figure 5: Reference PV and PV-PCM temperatures measured in Al Ain UAE, between 23/03/2014 till 02/04/2014

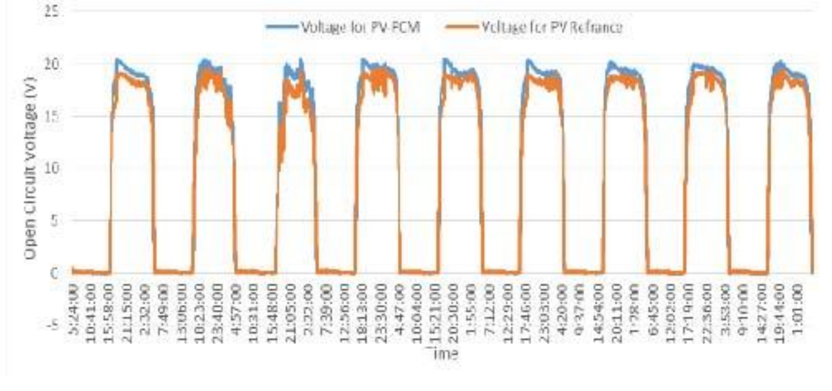

Figure 6: Reference PV and PV-PCM open circuit voltage measured in Al Ain UAE, between 23/03/2014 till 02/04/2014.

ECONOMIC EFFECTIVENESS

Authors have evaluated the use of PCM for lowering of PV temperature and extra power produced for Vehari, Pakistan which has very similar climate to the current site on experiments, Al Ain UAE. In the previous research, the PCM have been found cost effective with a return on investment about two years considering mass produced PV-PCM systems. Similiar results are expected for the current research which will be a subject of future publication for a year around testing of such systems [14]. The stored heat can be used for space or water heating. In case of UAE, the space heating demand is rare therefore Authors are currently conducting experiments for the extraction of stored heat for water heating applications in UAE and will soon publish the results. The hot water produced have larger demand in hospital buildings in UAE compared to residential developments.

CONCLUSION

The results obtained for testing PCM in higher temperature climate shows a promise for PV temperature regulation and power enhancement in the mild season of February where it always get back to solid. It needs still to be tested in the peak summer whether the PCM regenerates and gets back to solid at night by natural convection or it needs forced coolant flow to remove the heat contained in PCM.

ACKNOWLEDGMENTS

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NOMENCLATURE

AHU = Air handling unit

EER = Energy efficiency rating

R-value = Thermal resistance value

VFD = Variable frequency drive

WWR = Window to wall ratio

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The Role of Thermal Mass in Humid Subtropical Climate: Thermal Performance and Energy Demand of CSET Building, Ningbo

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ABSTRACT

The role of thermal mass in humid subtropical climate has always been intriguing. Located on the eastern coast of China, in humid subtropical climate zone, the Centre for Sustainable Energy Technology (CSET) building, Ningbo, is the first of its kind in the country. It is developed as an exemplar building which displays various energy efficient techniques to increase user comfort and reduce energy demand. Although, the use of heavyweight construction has always been controversial in such climates due to small diurnal range (10°C) and high humidity (65%-95%), the building possesses high thermal mass in the form of 300mm thick concrete walls and 400mm thick concrete slab. The objective of this study was to analyse the thermal performance of CSET building, Ningbo in terms of thermal comfort and energy demand, with respect to the high thermal mass. Through this study, it was also aimed to establish the role of thermal mass in humid subtropical climate zone. Parametric analysis was performed on the building using computer simulations, carried out on TAS Thermal Analysis Simulation Software, to obtain comparative results with and without night ventilation, for four cases: (i) As-designed case, (ii) Reduced building mass, (iii) Heavyweight building materials substituted with lightweight materials and (iv) Omission of the building's glass envelope. Results indicated that the as-designed case i.e high thermal mass coupled with night ventilation performs the best in terms of thermal comfort and energy demand and hence plays a vital role in the thermal performance of CSET building. It was further established that in humid subtropical climates, night ventilation, proper shading, controlled daytime ventilation and moderate internal gains could improve the performance of heavyweight buildings, such that they perform better than the traditionally accepted lightweight buildings.

Keywords: *humid subtropical climate, thermal mass, night ventilation, thermal comfort, energy demand*

INTRODUCTION

Thermal mass is said to function as a climate moderator as massive building envelopes can attenuate the temperature fluctuation and reduce the indoor peak temperature. Thermal mass has been defined by Yannas (1994) as the capacity of a building to store and release heat at different times of the day. Thermal capacity is expressed as "the energy required to raise the temperature of a layer of material". Usually, "higher the density of a material, higher is the resulting thermal capacity" (ibid).

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Therefore, buildings with high thermal capacity are termed as heavyweight and include all masonry construction, while buildings with low thermal capacity are thermally lightweight and include timber or steel frame construction (ibid). It is often believed that using thermal mass is a universally ‘good thing’ (Baker & Steemers, 2000). However, the benefits of the effect of thermal mass depend on several parameters such as climate conditions, building thermal properties, ventilation, thermal insulation, occupancy and internal heat gains.

Traditionally, it was believed that the use of thermal mass did not have any benefits in humid subtropical or warm-humid climates. According to Szokolay (2000), up to the mid 1980s it was considered preferable to have elevated, lightweight, cross-ventilated buildings in such climates. However, these traditional design principles were being questioned by researchers like Szokolay (2000) and Soebarto (1999) who have investigated the role played by thermal mass in warm-humid climates. Their studies suggested that the debate between the performance of heavyweight and lightweight buildings in such climates was futile as both constructions performed equally well, with heavyweight performing slightly better than lightweight buildings (see Figure 1).

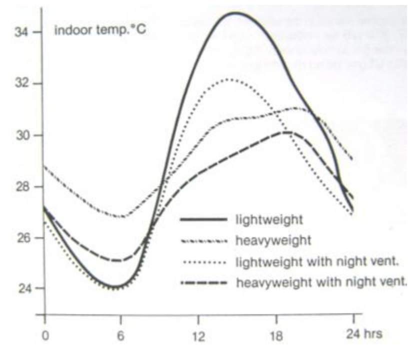

Figure 1 *Performance of lightweight and heavyweight buildings in warm-humid climate, Source: Szokolay, 1985 cited by Baker & Steemers, 2000*

Although much work has been done till date, more studies need to be conducted to ascertain the effects of the much debated use of thermal mass in humid subtropical climate. For the purpose of this study, an exapmlar building (using high thermal mass), located in humid sub-tropical climate was selected.

The Centre for Sustainable Energy Technology (CSET) building is situated in Ningbo (28˚51'-30˚33'N and 120˚55'-122˚16'E) which is located on the eastern coast of China, to the South of the Yangtze River Delta (see Figure 2.1) (Lau et. al. 2006). According to the most widely used world climate classification done by Köppen-Geiger (Kottek et. al. 2006), Ningbo lies in the humid subtropical zone. The building is developed as an exemplar building which displays various energy efficient techniques to increase user comfort and reduce energy demand. The building incorporates high thermal mass i.e. it is thermally heavyweight.

The climatic analysis of Ningbo revealed a diurnal range of about 10°C and a relative humidity of 65-95%. Due to the small diurnal swing and high humidity in summer, it was felt that the thermal mass may not perform as expected. Lau et al. (2006) also suggested that night ventilation may not be very effective in providing pre-cooling in summer. Due to these reasons, it was considered essential to analyse the role of thermal mass in CSET building. Through this analysis, it was aimed to re-establish the role of thermal mass in humid subtropical climate zone so that this study can be referred to by designers designing in similar climate all over the world.

CSET BUILDING, NINGBO

The CSET building, developed as a climate integrated design, promotes energy efficiency, generates its own energy from renewable sources, uses locally available materials with low embodied energy and harvests rainwater (Lau et al.,2006). Along with other climate responsive strategies, the building has internally exposed 300mm thick concrete walls and 400mm thick concrete slab. This implies that the building uses internally exposed thermal mass to minimize temperature fluctuations in summer & winter. The architectural drawings of the building are presented in Figure 2 (a), 2 (b) and 3.

The section shown in Figue 3 depicts the building functions. The laboratory, a workshop and an exhibition space are located in the semi-basement floor. While the research and teaching areas for post graduate students are situated on the second and third floor. The offices, a meeting room with staff kitchenette are all distributed on the fourth and fifth floor (see Figure 3).

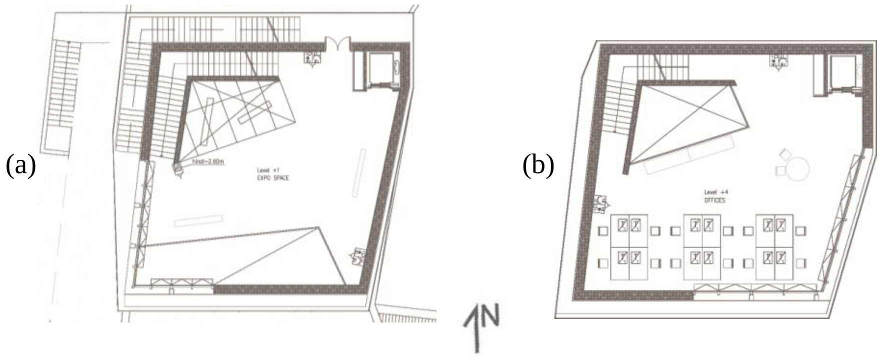

Figure 2 *(a) Ground floor plan (b) Third floor plan, Source: MCA*

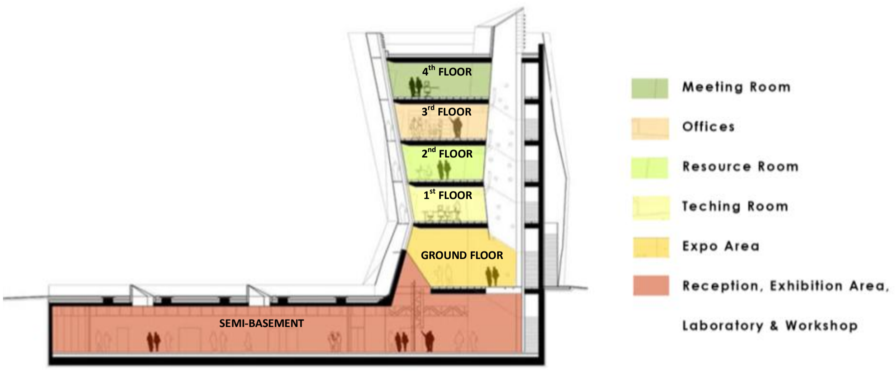

Figure 3 *Building function, Source: MCA*

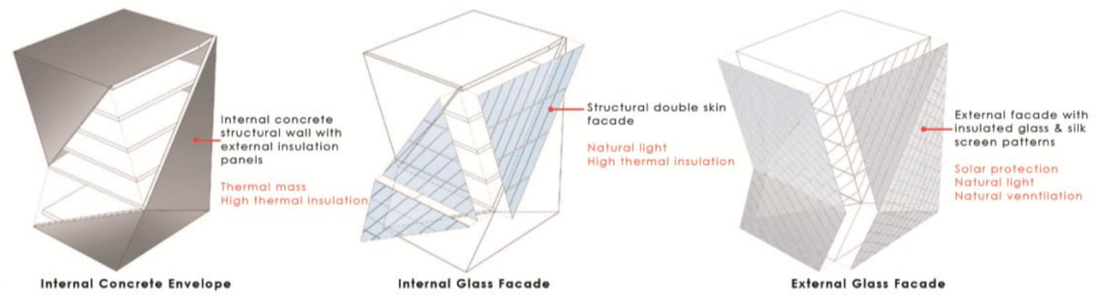

Figure 4 *The building envelope, Source: (MCA, SBE, 2006)*

The opaque parts of the building are made of externally insulated concrete and have openings for natural ventilation. The transparent parts of the building are made of high performance glass which in combination with the external façade provides thermal insulation while optimising daylight penetration into the internal spaces. The second skin makes an external envelope around the building. This external envelope is made of silk screen laminated glass in order to avoid direct solar penetration into the internal spaces (refer Figure 4). The double skin on the south side is sealed providing a thermal buffer, passive pre-heating in winter and exhausting unwanted warm air in summer. The skin on east and west walls is open and provides solar protection and vents excess solar gains.

METHODOLOGY

This research was based on thermal performance analysis of parametric variations in the building envelope which could be tested by performing computer simulations. The parametric analysis was performed for the following cases:

Case I: Base Case

I - a: Base Case without Night Ventilation

I - b: Base Case with Night Ventilation

Case II: Reduction in Mass

II - a: Reduced Mass without Night Ventilation

II - b: Reduced Mass with Night Ventilation

Case III: Lightweight Construction

III - a: Lightweight Walls without Night Ventilation

III - b: Lightweight Walls with Night Ventilation

III - c: Lightweight Walls and Suspended Ceiling without Night Ventilation

III - d: Lightweight Walls and Suspended Ceiling with Night Ventilation

Case IV: Omitting the Glass Envelope

IV - a: Omitting the Glass Envelope without Night Ventilation

IV - b: Omitting the Glass Envelope with Night Ventilation

The comparative analysis of the above mentioned cases helped in answering the much debated question about the difference in the performance of heavyweight and lightweight buildings in humid subtropical climate. The following considerations / assumptions were made for performing the dynamic thermal simulations on the software.

Comfort Range / Energy Demand. As per the climate analysis of Ningbo as well as review of available literature regarding comfort range, 19°C to 27°C was classified as the thermal comfort range for CSET building. Similarly, based on Pasivhaus and Keller Technology's standards, the benchmarking for heating and cooling demand for Ningbo is taken in the range of 30 KWh/m² to 40 KWh/m².

Building Analysis Software. The Building Thermal Analysis Program used for performing the analysis, the New Generation TAS v. 9.1.3a developed by Environmental Design Solutions Ltd. (EDSL). TAS, is a dynamic thermal simulation tool. It allows the user to model, zone and subsequently simulate the building to predict its energy consumption, CO2 emissions, operating costs and occupant comfort.

Model Geometry. The geometry of the model was created in accordance with the information provided on the architectural drawings. Due to the limitations of the software, the façades were modelled based on the assumption that they are vertical i.e. they were modelled without the inclination indicated in the drawings (See Figure 5 (a) and (b)).

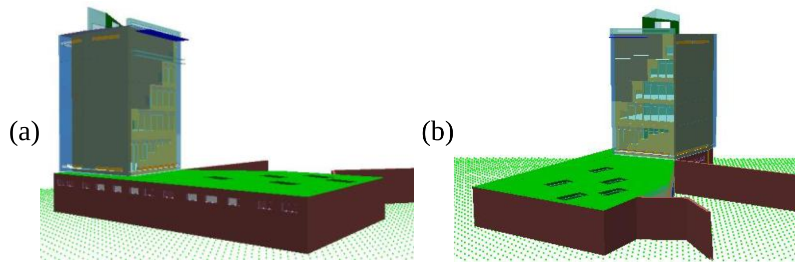

Figure 5 (a) South-west view of model (b) South-east view of model (the tilt on the south is not considered), Source: Created by author using TAS

Weather Data. The weather file used for the analysis was sourced from Energyplus and the nearest available location to Ningbo was Shanghai. After reviewing the two weather files, the difference between their temperature profiles were considered negligible. Therefore, the weather file of Shanghai was used for all simulations (refer Lau et all, 2006).

Building Elements. Information regarding construction materials to be applied to the various building elements like external wall, internal walls, floor, roof, glass etc. was obtained from Lau et al. (2006). Some of the specified materials were not available in TAS construction database; hence the closest to the specified were selected. For this reason, a slight variation occurred in the U-values of some of the building elements. The details of the building elements are as given in Table 1.

Table 1. Building Elements

S.No.	Building Element	Building Material	U-Value (W/m^2°C)
1	Externally insulated wall	300mm concrete with 120mm insulation	0.24
2	Internal wall	200mm concrete	1.9
3	Floor	400mm concrete	1.4
4	Basement floor	Concrete Slab with cavity insulation	0.4
5	Roof	Concrete	0.24
6	Openings in external wall	High performance clear glass	1.5
7	External glass envelope	Silk screen laminated glass	5.6

Internal Conditions. Based on the use of the space, assumptions were made regarding occupancy, equipments and lighting gains in the building and the same are presented in Table 2. These assumptions were kept constant throughout the study.

Table 2. Internal Conditions

Floor	Space	Occupancy (@ 80W/ person)	Equipment	Lighting
Semi-basement	Reception, exhibition, lab, workshop	15 persons	No equipment No equipment	None in summer, 6W/m2 in winter
Ground Floor	Expo area	3 persons	No equipment	None in summer, 6W/m2 in winter
First Floor	Teaching room	30 persons	30 laptops @ 80W per laptop	None in summer, 6W/m2 in winter
Second Floor	Resource room	15 persons	No laptops	None in summer, 6W/m2 in winter
Third Floor	Offices	10 persons	10 PCs @ 100W per PC	None in summer, 6W/m2 in winter
Fourth Floor	Meeting room	10 persons	No equipment	None in summer, 6W/m2 in winter

As mentioned earlier, the comfort range was classified as 19°C to 27°C. Simple natural ventilation was simulated for all cases. The aperture settings were such that the apertures began to open if the dry bulb temperature in the adjacent zone exceeded 23°C, and were fully open if the dry bulb temperature reached 26°C. The apertures began to close when the internal temperature exceeded the external temperature. The building is occupied from 8:00am to 6:00pm and for incorporating night ventilation, all windows were opened from 7:00pm to 8:00am, for all seasons except winter. The maximum wind speed was assumed to be 10m/s, beyond which the apertures began to close regardless of the temperature. An infiltration rate of 0.2 ach was considered.

No heating or cooling was modeled, as the intent of the study was to test the performance of the building with or without thermal mass, isolated from all heating and cooling strategies. For the purpose of calculating heating and cooling demand, another set of simulations were run for which the heating set point was taken at 19°C and the cooling set point was taken at 27°C.

Data Selection. For evaluating thermal comfort, firstly the dry bulb temperature was observed over a period of a week in summer (17th – 23rd July, warmest week), mid-season (15th – 21st October) and winter (18th – 24th December, coldest week). Secondly, the total number of occupied hours from the whole year, when the temperature exceeded 27°C was extracted for every zone for each case. As the occupied time for this building is 8:00am to 6:00pm, the total annual occupied hours is 3650. Finally, the energy demand was observed in terms of the total annual heating and cooling demand of the building. The internal gains due to equipments, lighting and occupancy were expressed in KWh/m² and remained constant throughout the study. The solar gains varied according to the building fabric.

COMPARATIVE ANALYSIS

The parametric analysis conducted for the specified cases revealed that the performance of the building deteriorates upon reduction in building mass. It was identified that the main benefit of a heavyweight building was that the variation in internal temperature was smaller and closer to the average external temperature than a lightweight building. In the lightweight substitute of the building, the fluctuations in internal temperature were larger and presented higher peeks than the heavyweight building as well as the ambient temperature (refer Figure 6). From the comparison of the building with and without the glass envelope, it was found that the thermal mass became more effective when it received lower solar gain since the low transmittance glass acted as a shading device for the building.

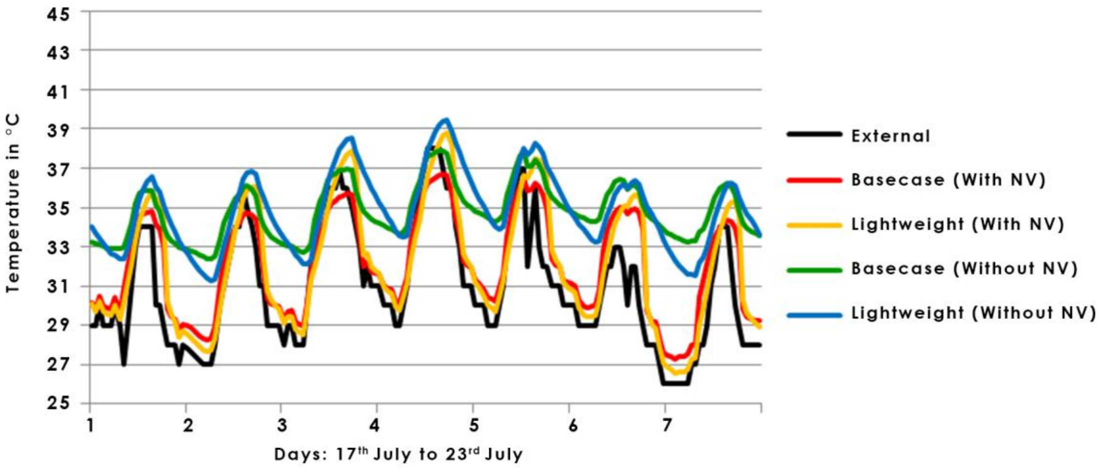

Figure 6 Indoor summer temperature profile: Basecase v/s Lightweight Construction, Source: Author

In general, for all cases, night ventilation (NV) enhanced the performance of the building. In summer, during the warmest week, the condition “with night ventilation” was found to perform better than “without night ventilation” for the Ground Floor, while the upper floor temperatures for the two conditions, were almost coinciding with “with night ventilation” performing better. Even though night ventilation assists in lowering the temperatures, they were still found to be above 27°C during the occupied hours implying that extreme summer conditions would result in overheating unless cooling is provided. During mid-season, all the temperatures lay in the comfort zone i.e. 19°C to 27°C. Although both lower as well as upper floors benefited from the effect of night ventilation, the benefits were more visible in in the lower floors. In extreme winter conditions, the internal temperatures lay out of the comfort range i.e. they were below 19°C.

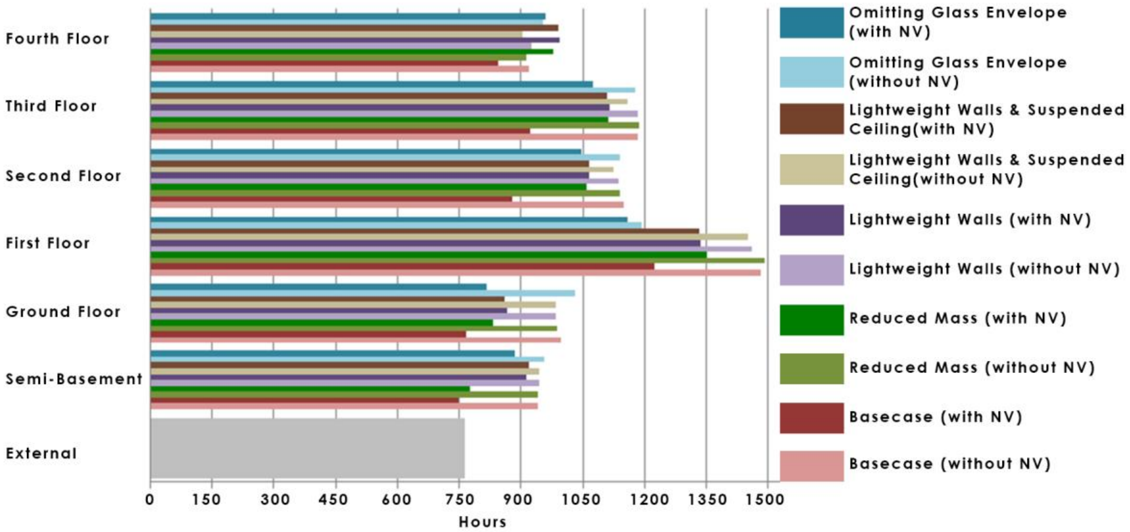

Figure 7 *Hours exceeding 27°C during occupied hours: Comparison between all cases, Source: Author*

During the 3650 occupied hours, the building was found to experience comfortable temperatures in mid-seasons. The number of hours when the ambient temperature exceeded 27°C, the upper limit of the specified comfort range, is 760. Even during the warmest summer days the building exhibited stable indoor temperatures, though at temperatures above the thermal comfort range i.e. 27°C. The graph shown in Figure 7 reveals that for all the cases, without night ventilation, the number of hours exceeding 27°C during occupied hours is similar in each zone. Night ventilation enhances the building performance and there is variation in the results for this condition among the various cases. For every zone, the Base-case, a combination of thermal mass and night ventilation works best. Floor wise analysis revealed that the first floor was the worst performing floor, probably due to very high gains from occupancy and equipments. The performance became better with night ventilation. The semi-basement floors performed the best as they had low occupancy and high thermal mass. The ground floor performed better than the upper floors in all cases. The ground floor experienced about 770 hours exceeding 27°C, i.e. similar to ambient, while for the upper floors the number was about 1010(refer Figure 7).

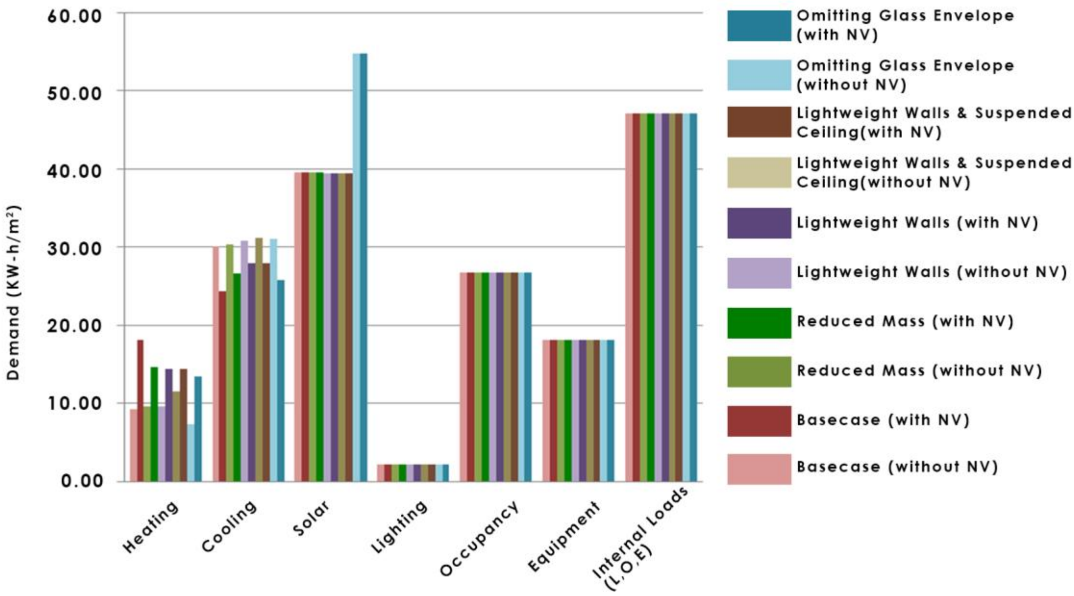

Figure 8 *Annual loads: Comparison between all cases, Source: Author*

In terms of energy demand, although the annual cooling load reduced with the incorporation of night ventilation, the annual heating load increased (refer Figure 8). Due to the limitation of the software, for some days in spring and autumn when the ambient temperature was very low, although night ventilation was not required, the apertures were still open. This might have resulted in an over-estimate of the heating loads. The total annual heating and cooling load for the building was found to be 39 KWh/m² and 42 KWh/m² for Base-case without night ventilation and with night ventilation respectively. These values are higher than the Passivhaus standard of 30 KWh/m²; however the values lie in or slightly above the specified range of 30 KWh/m² to 40 KWh/m² for heating and cooling. This implies that there is scope for improvement in the thermal performance of CSET building.

The lower floors (semi-basement and ground) in the building perform well due to low occupancy and equipment gain, while the upper floors (1st to 4th) suffer due to higher gains and lesser openings. Therefore it is strongly believed that reducing the gains and provision of more openings in the upper floors would improve the performance of the building.

CONCLUSION

From the above analysis, a broader conclusion can be drawn that a heavyweight building i.e. a building with high thermal mass, when coupled with night ventilation, appropriate shading and moderate internal gains from occupancy, lighting and equipments, performs better than a lightweight building in a humid subtropical climate even though this climate has small diurnal range and high humidity. This conclusion is in conjunction with the results of the studies conducted by Szokolay (2000) and (Soebarto, 1999) on the role of thermal mass in warm- humid climate.

Although, this research was contextually bound to one building in Ningbo, China, the inferences made would be helpful in establishing the general performance of thermal mass in humid subtropical climate which would assist building designers designing in this climate anywhere in the world. However, as the design and microclimate of each building plays a very important role in its performance, there are limits to the generalisability of the results. For this reason, it will not be advisable to prepare design guidelines based on the analysis of only one building. Based on a similar methodology as followed in this research, further research may look at thermal performance analysis of more intitutional buildings in this climate zone. Due to high relative humidity associated with humid sub-tropical climate, there is risk of condensation occurring due to contact of moist air with cold internal surfaces in buildings. As an extention to this study, further research may test the risk of condensation associated with lightweight and heavyweight construction in humid sub-tropical climate zone.

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Extensive Green Roofs: Potential for Thermal and Energy benefits in buildings in central India

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ABSTRACT

Any building essentially contains walls and roof which are directly exposed to external environment. Undoubtedly the most critical part of the whole building surface is the roof as it receives the maximum solar radiation particularly in summer months thereby increasing the heat load in buildings. Many studies have been conducted over the years to consider the potential building energy benefits of Extensive Green Roofs. There is a sharp increase in the number of countries that conduct green roof research in the last two decades realizing its importance globally. A green roof offers a building and its surrounding environment many benefits, which include: storm water management, improved water run-off quality, improved urban air quality, extension of roof life and a reduction of the urban heat island effect; other benefits also include enhanced architectural interest and biodiversity.

Green roofs cool through latent heat loss and improved reflectivity of incident solar radiation. This suggests that green roofs are predominately seen as a passive cooling technique. Intensive literature review shows that barely any research is done in Indian context for usage of green roof. Green roofs are hardly visible in Indian context; probable reasons are lack of awareness, socio-cultural backgrounds and cost factors. Also it has not been given importance in local building bylaws. Moreover, an in-depth research is needed on green roof in Indian climatic conditions as we have longer sunny days with higher solar intensity (thereby increasing load on air conditioning). It may prove to be important 'investment' in longer terms considering the huge energy requirements in the future.

The paper also highlights study in composite climate of central India with high global horizontal irradiation. It highlights thermal simulation modelling using Autodesk Simulation CFD (Computational Fluid Dynamics) software, used as a tool to validate the summer cooling potential of extensive green roofs.

Key words: Extensive Green Roofs, Passive and Low Energy Architecure, Energy consumption in Buildings, Simulation Modelling

INTRODUCTION

Walls only receive about two-thirds of the maximum solar radiation that falls on the roof, and considerably less than this on the wall which faces away from the equator. The period of reception of direct solar radiation on walls is shorter than on roofs: east and west walls will only receive direct sunlight for half of the day. Undoubtedly the most critical part of the whole building surface is the roof.

In any location near the equator this receives the greatest amount of solar radiation, thus the highest heat load. The horizontal roof receives maximum solar radiation during the summer and generally is the main path of heat flux entering the living space.

City surfaces are prone to absorb and release large quantities of heat thereby creating urban heat-island effect. Urban heat-island (UHI) is a common phenomenon where urban temperatures are significantly higher than those of its surrounding suburban and rural areas in summertime. UHIs can affect communities by increasing summertime surface temperature of building envelopes and infrastructures; intensifying thermal discomfort; elevating cooling energy use and peak energy demand; adding air pollution; and raising risks in heat-related illness or mortality. A higher air temperature tends to increase cooling needs and reduce working efficiency of cooling systems for built environments, resulting in higher power demand and energy use.

The roof of a building can be fully or part covered with a layer of vegetation known as a Green Roof. A green roof is a layered system comprising of a waterproofing membrane, growing medium and the vegetation layer itself. There are two main classifications of green roofs; extensive and intensive. Extensive green roofs have a thin substrate layer with low level planting, typically sedum or lawn, and can be very lightweight in structure. Intensive green roofs have a deeper substrate layer to allow deeper rooting plants such as shrubs and trees to survive. Extensive systems offer the most cost effective solution over intensive types. Extensive roofs are the preferred option for retrofitting onto existing buildings as the structural capacity of the roof will often not have to be increased. Green roofs greatly reduce the proportion of solar radiation that reaches the roof structure beneath as well as offering additional insulation value.

India is experiencing an unprecedented construction boom. The country doubled its floorspace between 2001 and 2005 and is expected to add 35 billion m^2 of new buildings by 2050. Buildings account for 35% of total final energy consumption in India today, and building energy use is growing at 8% annually. Studies have shown that carbon policies will have little effect on reducing building energy demand. Various researchers have predicted that, if there are no specific sectoral policies to curb building energy use, final energy demand of the Indian building sector will grow over five times by the end of this century, driven by rapid income and population growth. The growing energy demand in buildings is accompanied particularly by an increase in electricity use. This also leads to a rapid increase in carbon emissions and aggravates power shortages in India. Growth in building energy use poses a challenge for the Indian government.

It becomes very important for architects, designers, builders and owners to focus on building designed with Passive measures, design tools and methods thereby reducing/kerbing energy consumption in buildings thereby moving in the direction of sustainability.

This paper addresses the potential building energy reduction benefits arising from the enhanced thermal properties of a Green Roof making it essential part of passive design and low energy architecture.

THE STUDY CASE

Variation of the solar thermal gain in a typical room with green roof using Autodesk Simulation CFD (Computational Fluid Dynamics) software as an analysis tool is investigated in this study as compared to that of a conventional bare roof situated in the state capital of Chhattisgarh state, Raipur having composite climate. Simulation is performed for one typical solar day corresponding to the peak summer season and generally peak temperature of the day in a given time so as to understand the difference between conventional and green roof outcomes. Because this scenario simulates a design day, the simulation of air movement is done with natural convection only.

Geometry

The room admeasuring 6.0 M X 3.5 M consisted of two windows on the southern side and a door on the northern side, east-west being the longer axis of the room, which is naturally ventilated had been taken as a case for the study. The construction of the room is of RCC framed structure having conventional RCC beams, columns, floor and roof along with brick work (0.23 M thick) covered with cement plaster as infill. Total height of the room taken including parapet is 4.05 M and interior room height is 3.0 M.

The green roof consists of a water proofing membrane (thickness taken as: 0.01 M), growing media: soil (thickness taken as: 0.15 M) and green cover: grass (thickness taken as: 0.10 M)

Material Properties

Table 1. Material Properties for Simulation Modeling

Material	Thermal Conductivity (W/m-K)	Resistivity (K-m/W)	DENSITY (kg/m3)	SPECIFIC HEAT (J/kg-K)	EMISSIVITY
Air (variable) (void)	0.02563	-	Equation of state	1004	1
Brick with plaster: walls	1.44	0.69	2100	875	0.94
Glass (window)	0.78	1.28	2700	840	0.92
Hardwood (door)	0.16	6.25	720	1255	0.8
Steel concrete cement (floor, roof slab, columns & beams)	1.75	0.57	2400	840	0.92
Water proofing membrane	1	1	950	837	0.8
Growing media: Soil	1	1	766	1000	0.92
Grass	0.115	8.69	500	1380	0.3

Simulations

The simulations are performed for peak summer hours of **2:30 PM on 30th of May (Figure 1 to Figure 5).** Considering the fact that because of time lag, temperatures in late hours than afternoon peak temperatures may give varied results; simulations are also done with the same parameters on the same day changing the time only to **6:00 PM in the evening (Figure 6 to Figure 10).**

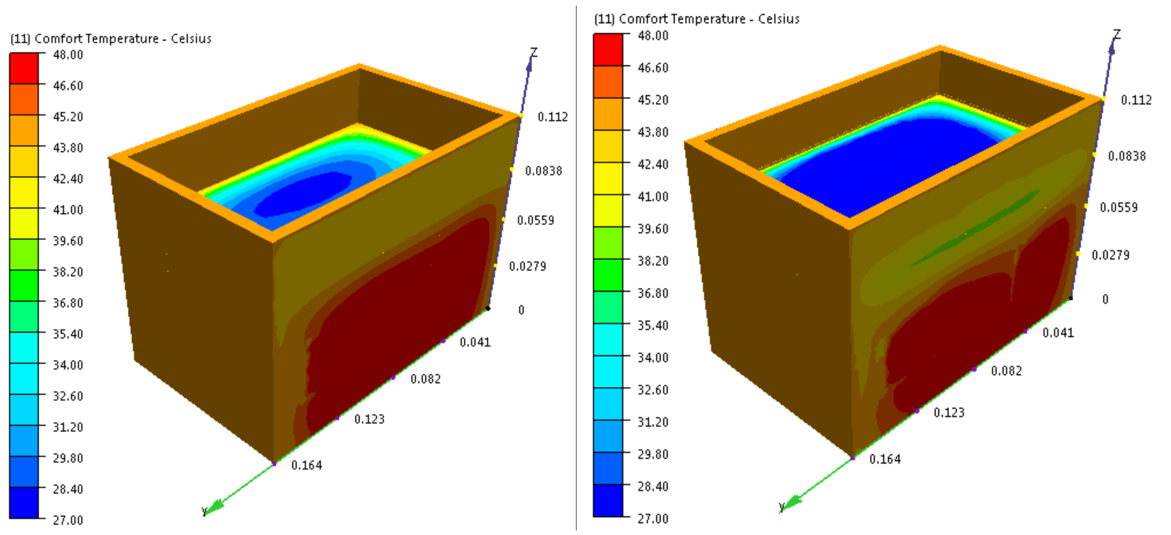

Figure 1 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting external surface temperatures around the room and roof)*

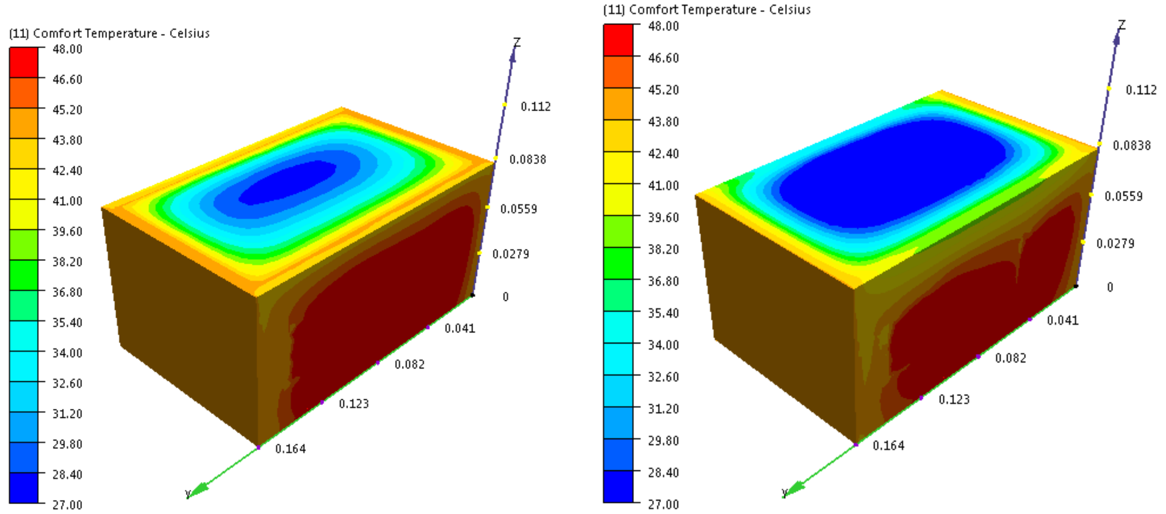

Figure 2 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting external surface temperatures around the room and roof)*

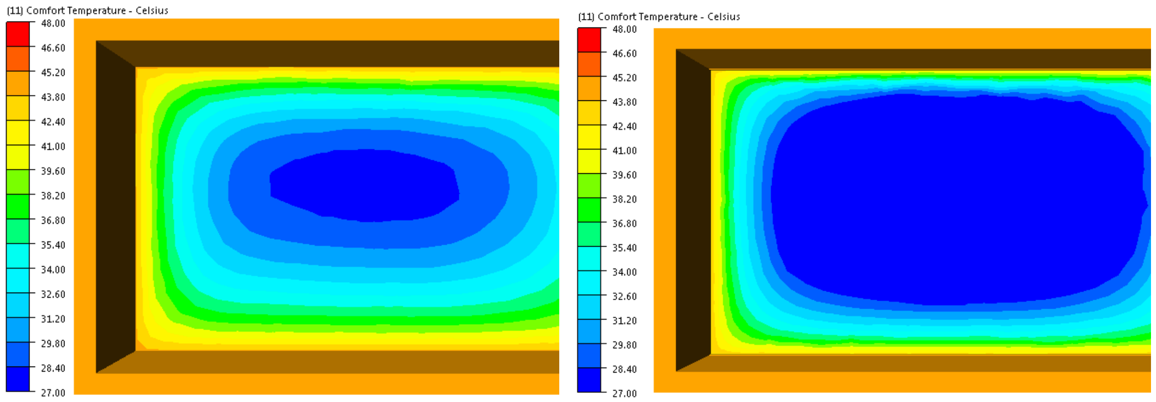

Figure 3 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting external surface temperatures around the roof)*

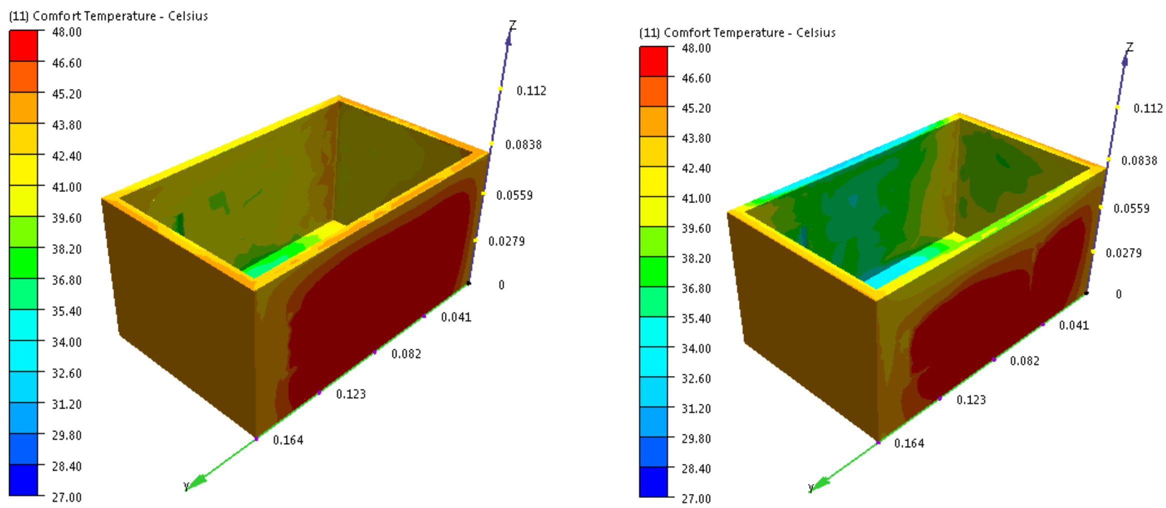

Figure 4 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting internal and external surface temperatures)*

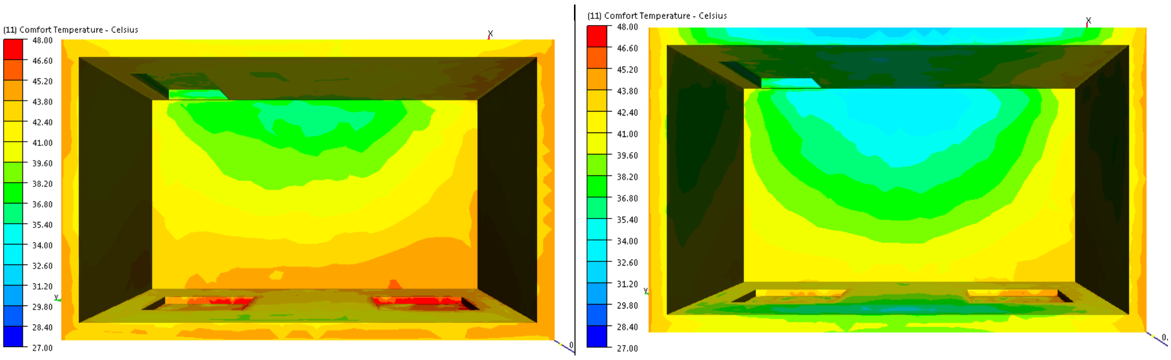

Figure 5 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting internal surface temperatures)*

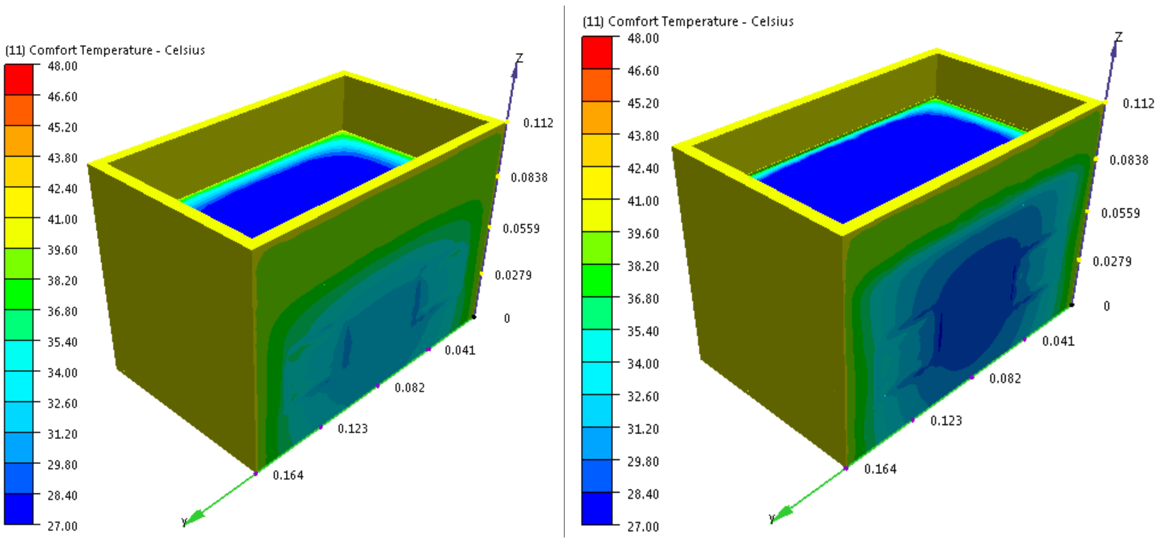

Figure 6 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting external surface temperatures around the room and roof)*

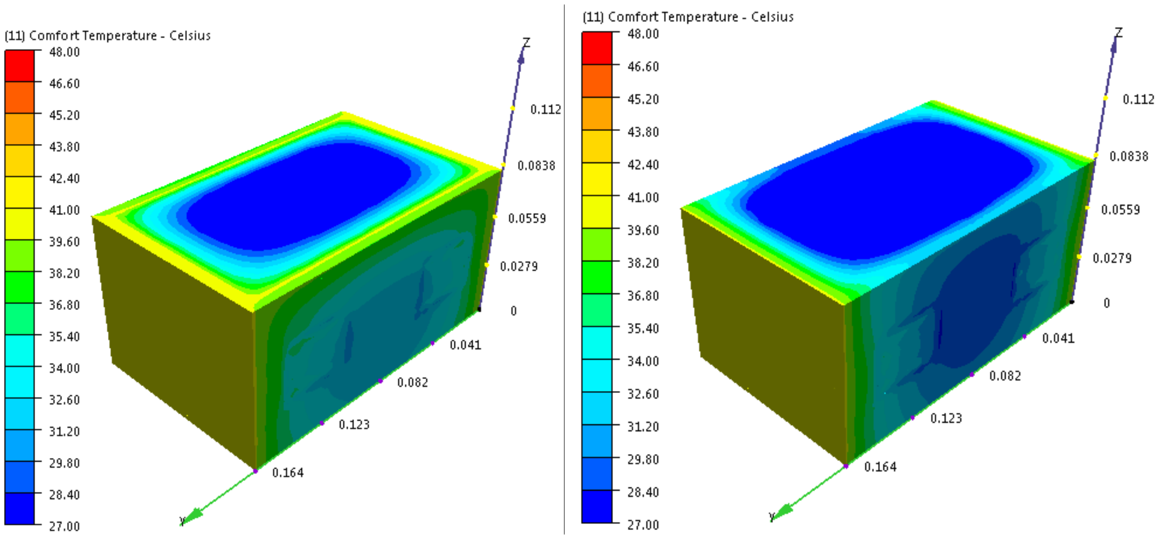

Figure 7 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting external surface temperatures around the room and roof)*

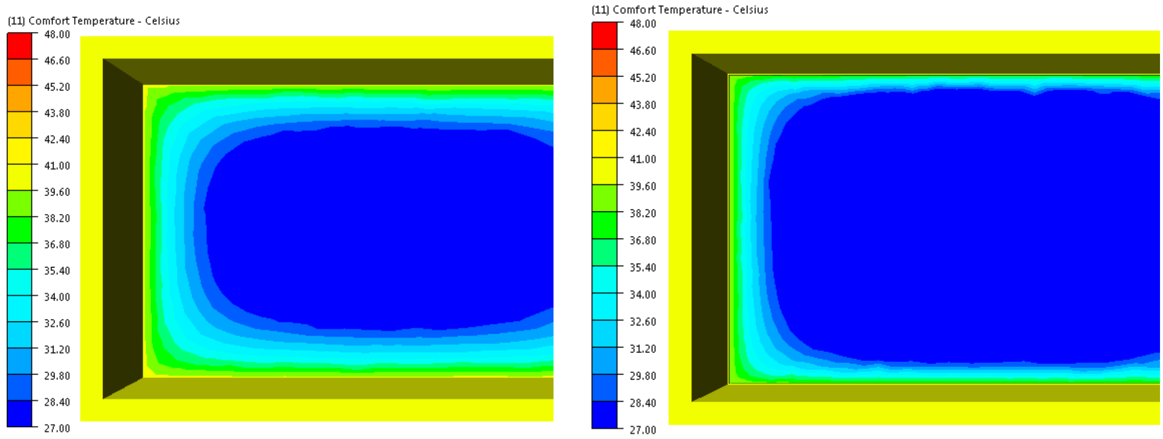

Figure 8 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting external surface temperatures around the roof)*

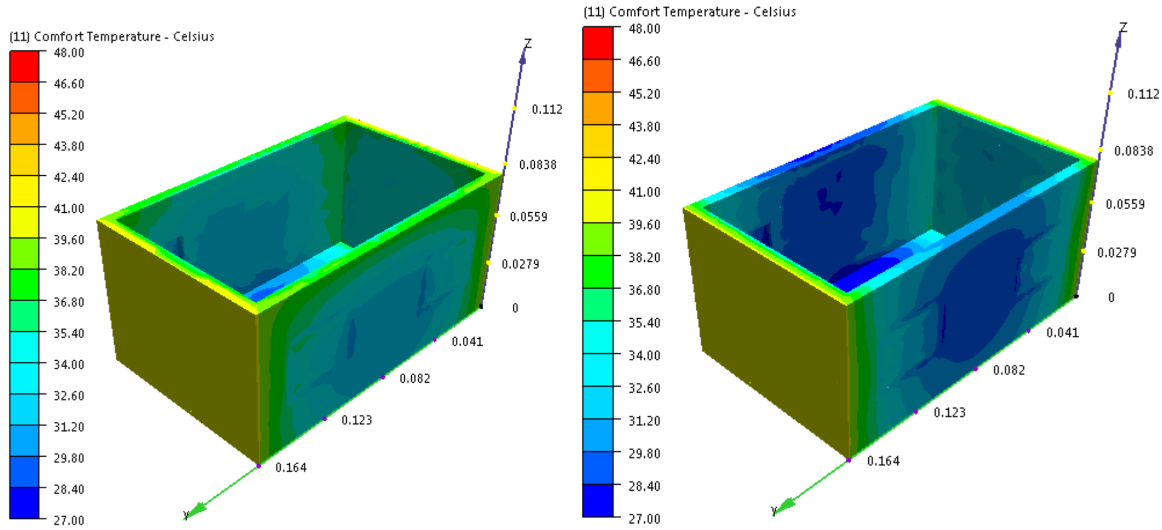

Figure 9 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting internal and external surface temperatures)*

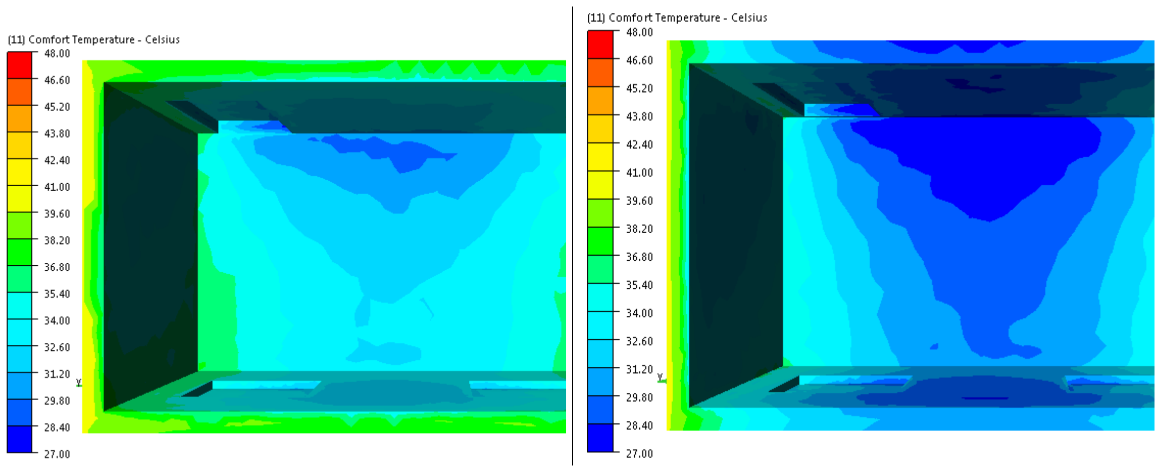

Figure 10 *(a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting internal surface temperatures)*

RESULTS

As shown **in Figure 1 to Figure 5**, upto 4°C reduction in temperature difference is visible in simulation modeling above the green roof as well as inside the room in given location and environmental conditions as compared to that of bare conventional roof.

And in the same model changing timings of the simulation to 6:00 PM (shown **in Figure 6 to Figure 10**), shows difference more than 4°C temperature i.e interior of the room will be more than 4°C cooler because of the presence of a green roof and similarly temperatures above the green roof also show similar differences.

CONCLUSION

Review of various scientific research works shows the importance and potential of green roof in numerous ways. Energy required for conditioning of spaces is aggravated in urban areas through the exhaustion of natural resources spent for electricity production (electricity production in the state of Chhattisgarh, India is by coal fired thermal power plants). Harnessing conventional fossil fuels and heat emissions by AC systems further add to the temperature increment in the environment. Planting a green roof will reduce *a.* exterior temperatures: therby controlling micro climate because of plant's presence and will reduce the urban heat island effect and *b.* inside temperatures: thereby reducing cooling loads inside the buildings.

The analysis of the simulations done with the help of computational fluid dynamics (CFD), clearly highlight the importance of a green roof as a passive design measure to be incorporated in buildings which would decrease the cooling requirements or the burden on the Air Conditioning systems for Raipur city in geographical location of the state of Chhattisgarh in central India.

An extensive review of the computational fluid dynamics (CFD) simulation results have exposed the following key factors when assessing their energy saving potential in the context of building use:

1. Observations of simulations providing green roofs in the buildings in the city of Raipur showed that green roofs are effective in reducing heat flow through the roof, thus lowering the energy demand for space conditioning in the building.
2. The green roof was effective in reducing high temperature and temperature fluctuations experienced by the roof membrane in conventional roofing system in the summer.
3. Since the average mean temperature was greater then comfort level temperature therefore, thermal comfort cannot be achieved only by providing green roof but it can reduce the load on air conditioning systems to considerable levels.
4. Results proved highly satisfactory and provided enough confidence for the study to be extended further for a larger solution space in real life measurements.

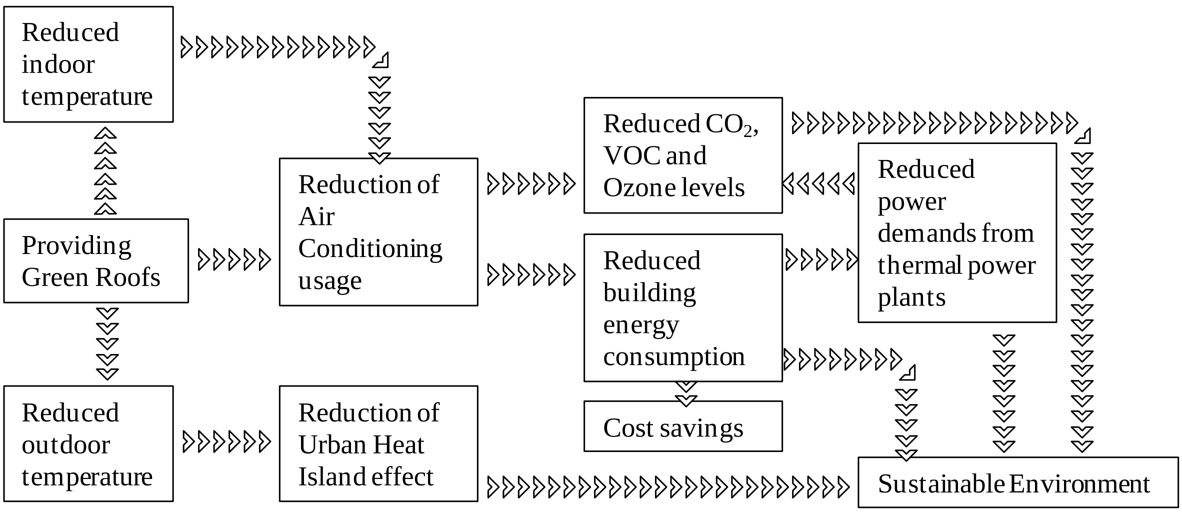

***Figure 11** Benefits of Providing Green Roofs*

Enormous use of ground for various purposes has lead to disappearance of green planted surfaces. In order to prevent dangerous and uncomfortable urban heat island effects the indispensable need of planted surfaces is quiet inevitable as is confirmed by many researchers. For example, a study estimated that an increase of 1°C in air temperature would require the addition of about 500 megawatts (MW) for air-conditioning of buildings in the Los Angeles Basin. Similar air temperature increases in urban areas are taxing the ability of developing countries to meet urban electricity demand while raising global greenhouse gas (GHG) emissions associated with energy use and power generation. Space constraints have further reduced the applicability of green surfaces in various areas surrounding the building envelope. Consequently, planting green roofs become very promising and stabilizing choice in the present scenario.

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Session 6A : Material technology

PLEA2014: Day 2, Wednesday, December 17
14:10 - 15:50, Faith - Knowledge Consortium of Gujarat

WinOpt – An Early Stage Design Tool for Optimizing Window Parameters

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ABSTRACT

To help architects and designers make early design decisions, an online tool (WinOpt) has been developed. WinOpt optimizes various components associated with the design of windows, such as Building orientation/Azimuth Angle (angle with respect to North), Aspect Ratio, WWR (Window Wall Ratio), SHGC (Solar Heat Gain Coefficient) of glass used for windows, and various local shading strategies such as overhang and side fins. WinOpt performs annual energy simulations for a given location using EnergyPlus. It uses an optimization tool in the back end (GenOpt) to reduce the few million simulations to a few hundred, thus helping in making rapid design decisions. WinOpt optimizes the design to minimize the operational energy for conditioned buildings and could maximize thermal comfort for unconditioned buildings. It also has a parametric option where parametric simulations are performed for selected values for various input parameters. This can help the user understand the spectrum of design solutions. Since EnergyPlus can evaluate both thermal comfort conditions and energy consumption in a building, WinOpt could help in design decisions for low energy/ net zero energy buildings.

INTRODUCTION

Among the various end use energy consuming sectors, buildings form a significant portion. There have been various efforts to reduce building energy consumption during design as well as operational phases. Most of the solutions could be used in a cost effective manner when incorporated during the building design phase. To evaluate the performance of various energy conservation measures, there are various simulation tools available. A list of these tools is provided at the US Energy Efficiency and Renewable Energy website (Building Technologies Program: Building Energy Software Tools Directory, 2013). A comparison of available tools can be found at Crawley B. D. et al. (2008).

There are various tools available that can help in early design. Autodesk Vasari (2013) focuses on conceptual building design using both geometric and parametric modeling. It supports performance-based design via integrated energy modeling and analysis features. EnergyPlus (Building Technologies Program: EnergyPlus Energy Simulation Software, 2012) is one such tool which was developed by the U.S Department of Energy. During the design phase of a building, EnergyPlus allows the user to pre-compute the energy usage and thus optimize the building design. EnergyPlus performs a whole building energy simulation.

COMFEN (2013) is a tool designed to support the systematic evaluation of alternative fenestration systems for project-specific commercial building applications. It dynamically simulates the effects of these key fenestration variables on energy consumption, peak energy demand, and thermal and visual comfort. The results presented in graphical and tabular format within the simplified user interface for comparative fenestration design cases help users move toward optimal fenestration design choices for their project. COMFEN uses EnergyPlus as its computational engine.

Many times, architects and designers face the situation where the combinations of Energy Conservation Measures (ECMs) available to them can run in to few millions. Further, larger simulation run time for building simulation model could be exhaustive in terms of cost and time. Also, for large models, higher simulation run time could lead to a delay in the optimization process.

Various building energy optimization tools are currently available to the users. GenOpt (2013), a tool developed by Lawrence Berkeley National Laboratory, can optimize problems where the cost function is computationally expensive and its derivatives are not available or may not even exist. Another tool, BEopt (2013), provides capabilities to evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings. DesignBuilder (2013) has a parametric analysis facility that is useful for searching 'optimal' designs.

To find out optimization solution for their buildings, user needs to have expertise in both optimization tools and simulation tools. There is a need for tools where users can address the problem directly, without learning simulation and optimization tools. During the early design stage, architects are the main performers of energy simulation (Bambardekar et al., 2009). The designs are more conceptual, not specifying the complete details of the buildings. Further, there are large numbers of ECMs to be considered for the building. A few quick simulations need to be performed and optimal choices need to be identified for a sustainable design. In producing the WinOpt tool described here, we have considered some of the key factors involved in the design of a façade and developed a tool that can minimize the operational energy for conditioned buildings and maximize thermal comfort for unconditioned buildings.

To reduce the direct solar heat gain into the building, one needs to optimize the design elements of a window. A few of these factors are:

1. Building orientation of the building with respect to true North
2. Aspect Ratio of the building (Length/Breadth ratio of the building)
3. Window-Wall Ratio (WWR)
4. The type of glass in the windows
5. Details of shading devices such as depth of the overhangs and side-fins

To compute the energy consumption of a building, one needs details such as type of building, operational schedules, internal loads, and Heating Ventilation and Air Conditioning (HVAC) systems. Most of these variables are provided as default values in the simulation model so that a user can directly select their optimization variable, provide an acceptable range of values, and view solutions.

DESCRIPTION OF THE TOOL

WinOpt is a tool that performs a multi-parameter optimization for reducing the energy consumption of a building. WinOpt achieves this by using EnergyPlus to compute the energy consumed by the building and using GenOpt for optimizing the user-selected design parameters. The algorithm chosen for optimization by GenOpt is a hybrid of the Generalized Pattern Search (GPS) algorithm and the Particle Swarm Optimization (PSO) algorithm, which is used to initialize the search. These algorithms can perform optimization for both continuous and discrete independent variables. The continuous independent variables are Azimuth angle, WWR, Overhang depth, and Aspect ratio, and the discrete independent variable is the glass type of the window.

WinOpt is being developed as a web-based application. The tool is developed on Apache/2.2.16 (UNIX) and Web pages are developed in PHP and use JavaScript/jQuery Technologies. At the back end, socket programming has been implemented, the code for which is written in the C language. The inputs submitted from the User Interface (UI) are pre-processed by a PHP script that generates the corresponding EnergyPlus Input Data File (IDF) for the simulation. The IDF name and the weather file name are then sent to a bash script that manages the simulations while the front end shows the progress of the simulations. Once the simulations are done, the UI is redirected to the results page, which shows the results. The architecture of the tool is shown in Figure 1.

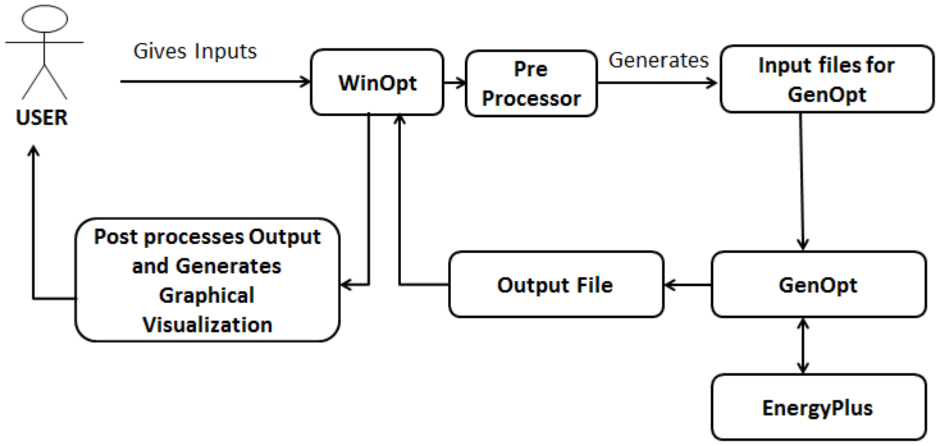

Figure 1 Work flow diagram of WinOpt

First, the tool takes the static parameters, which are the location of the building and HVAC type to be used in the building, as input. After the static parameters, it takes the ranges of the various variable parameters for which the building design is to be optimized. It then uses EnergyPlus and GenOpt to perform simulations in order to get an optimal output. There is also an option to perform parametric simulations on user specified values without any optimization, to give the user a complete spectrum of possible outputs for analysis.

In the tool, four different types of HVAC systems are available for selection – Packaged Terminal Heat Pump (PTHP), Packaged Single Zone (PSZ)-HP, Central Air Conditioning with a water cooled chiller, and Central Air Conditioning with an air cooled chiller. Each building type can be selected with any one of the available HVAC options listed in Table 1.

Table 1: Input parameters for different HVAC systems

S. No.	Parameter	PTHP	PSZ-HP	Central AC Water cooled	Central AC Air cooled
1.	Cooling Type	Direct Expansion coil	Direct Expansion coil	Water cooled screw chiller	Air cooled chiller
2.	Heating Type	Electric Heat Pumps	Electric Heat Pumps	Electric Resistance	Electric Resistance
3.	Fan Control	Constant Volume	Constant Volume	Variable Air Volume	Variable Air Volume
4.	Coefficient of Performance (COP)	2.8	3.0	5.5	3.1
5.	Heating Seasonal Performance Factor (HSPF)	1.91	1.91	Not Applicable	Not Applicable
6.	Air-side economizer	None	None	None	None

S. No.	Parameter	PTHP	PSZ-HP	Central AC Water cooled	Central AC Air cooled
7.	Heat Recovery	None	None	None	None
8.	Zone air set point	Cooling 24°C Heating 20°C	Cooling 24°C Heating 20°C	Cooling 24°C Heating 20°C	Cooling 24°C Heating 20°C

When GenOpt is used in the optimization mode, a series of random variable combinations are generated and simulations are performed to identify the low energy combinations. The optimization algorithm narrows down its search to the least energy consuming combinations from the above step. This leads to a clustering of variable combinations that produce low energy use. This could mislead a user about the range of solutions that are available. In order to make the user be more aware and cautious about the solution sets that are available, the option of performing a parametric simulation is also provided. Parametric simulation is a brute force method for performing simulations for all the possible combinations. This is time consuming but provides a full spectrum of results. Therefore, it would be useful for the user to be able to choose a limited set of variables for use in the parametric simulation based on the results from the optimization mode. Both these methods are compared in Table 2.

Table 2: Comparison of optimization and parametric mode

	Optimization mode	Parametric mode
Number of simulations	Low	High
Time	Low	High
Knowledge about ECMs applicable for the given design	No	Yes

A case study that illustrates the operation of GenOpt and the difference between parametric and optimization results is presented in the following section.

CASE STUDY

Location – Hyderabad, India
Building Type – Office
Building Footprint – 100 sq.m
Operation schedules – Mon – Fri (09:00 AM – 06:00 PM)
HVAC system – PTHP

Table 3 Input variables for optimization

S.No.	Parameter	Minimum	Maximum	Step Value
1	Building Orientation (°)	0	90	10
2	Window Wall Ratio (%)	20	80	10
3	Overhang Depth (m)	0.2	1	0.1
4	Aspect Ratio	1	2	0.1

Input parameters and ranges used in the optimization mode are listed in Table 3 and the four different values of glass types used are listed in Table 4.

Table 4 Glass types for optimization

S.No.	Glass type	U- value (W/sq.m-K)	Solar Heat Gain Coefficient (SHGC)	Visible Light Transmittance (VLT) (%)
1	Type-1	1.5	0.25	50
2	Type-2	3.72	0.28	27
3	Type-3	1.5	0.20	35
4	Type-4	5.7	0.67	67

Input parameters and ranges used in the parametric mode are listed in Table 5 and different values of glass types used for performing the simulations for parametric mode are listed in Table 6.

Table 5 Input variables for the parametric simulations

Parameter	Value 1	Value 2	Value 3	Value 4	Value 5
Building Orientation (°)	0	45	90	135	180
Window Wall Ratio (%)	20	40	50	60	80
Overhang Depth (m)	0.3	0.5	0.8	1.2	1.5
Aspect Ratio	0.6	1.0	1.3	1.5	1.8

Table 6 Glass parameters used for the parametric simulation

S.No.	Glass type	U- value (W/sq.m-K)	SHGC	VLT(%)
1	Type-1	3.3	0.15	15
2	Type-2	3.3	0.25	25
3	Type-3	3.3	0.40	40
4	Type-4	3.3	0.60	60
5	Type-5	3.3	0.85	85

The results can be broadly categorized in two formats:

1. An 'N' dimensional interactive graph as shown in Figure 2 and 3. Using this graph, the user can get insights such as which combination of variable parameters produces the best performance in terms of energy use. The user can also study the impact of various parameters on the performance of the building.
2. A 'Bitmap' visualization of the data as shown in Figure 4. This visualization is available only for parametric simulations. This visualization is useful for finding and understanding clustering (if it exists) in the energy consumption of the building. Therefore, using this visualization, the user can study the parameters that have a major impact on the energy consumed by the building.

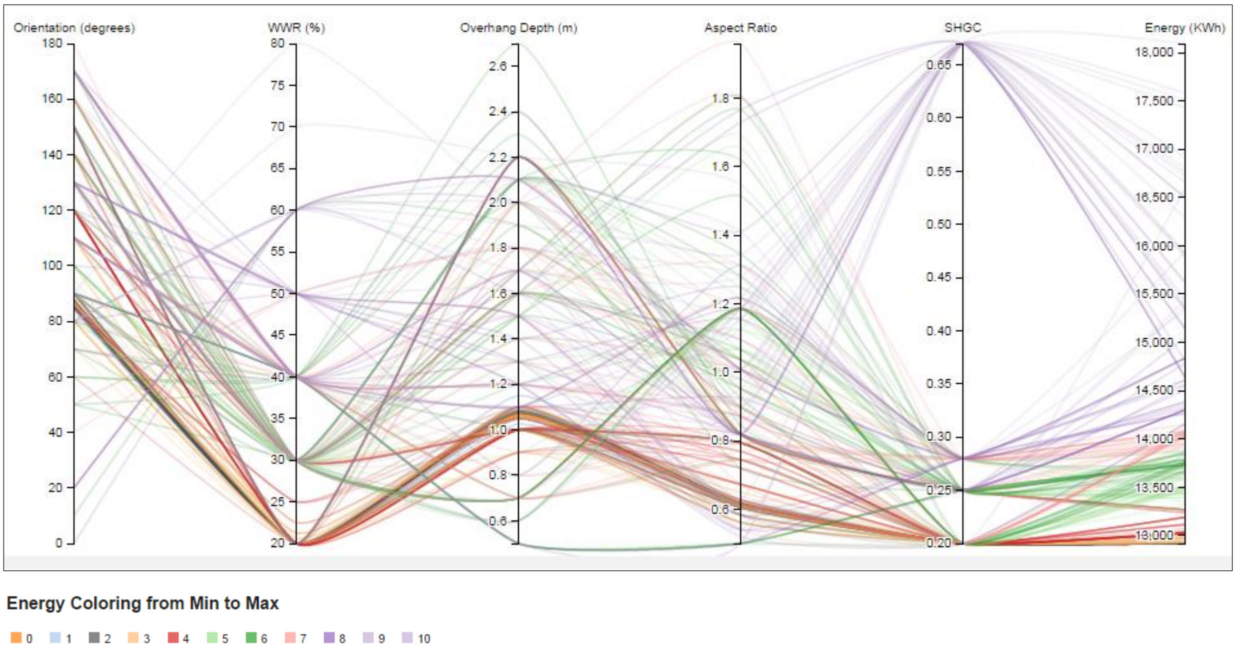

Figure 2 Near-optimal solutions obtained using GenOpt, which are used to inform the selection of parameters for use in the parametric study

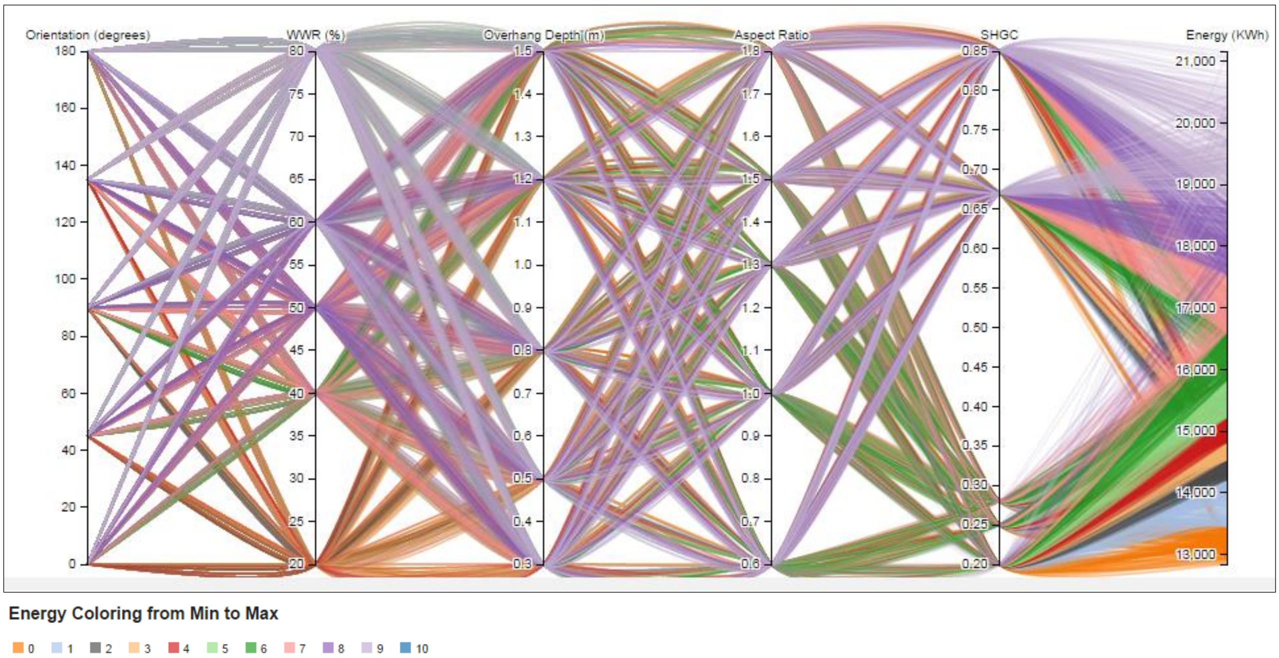

Figure 3 Results obtained by performing parametric simulations

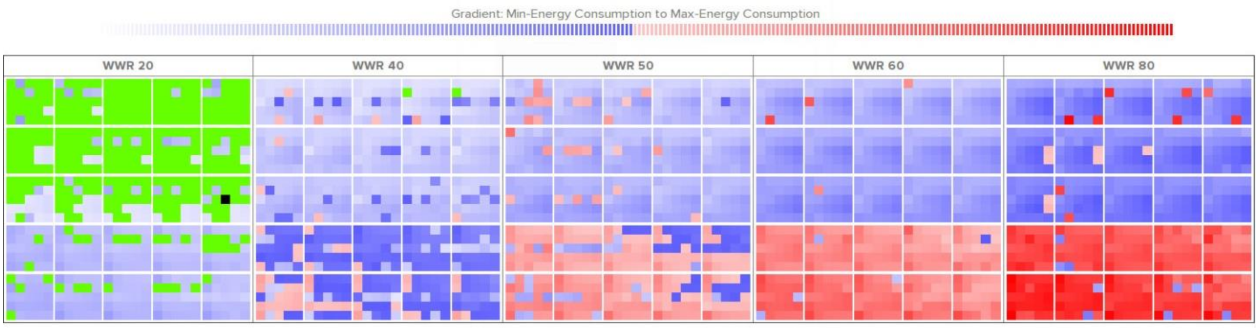

Figure 4 Bitmap visualization of the data

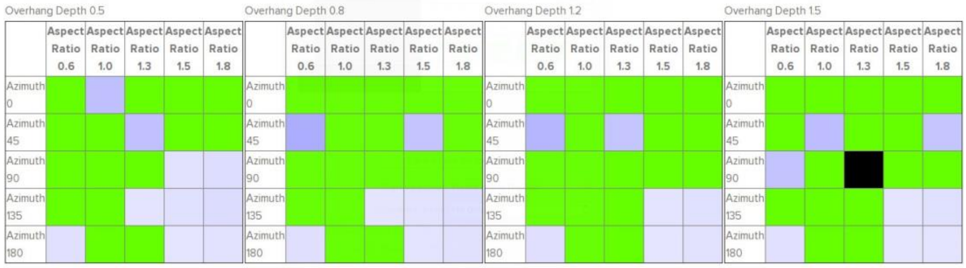

Figure 5 Bitmap visualization of the data with Zoom option

The following observations can be made from the Bitmap Visualization from Figure 4 & 5:

1. The **Green Region** in the graph shows the areas that are close to the minimum energy as given by parametric simulations (within 5%). As can be seen, this could be achieved by diverse combinations.
2. The **Black Point** in Figure 5 shows the minimum energy value obtained by parametric simulations.
3. The **Red Region** shows the area of maximum energy consumption which appears to be highly clustered in regions of high WWR and high SHGC.
4. The color gradient in graph goes from Green to Blue to Red, where green represents the minimum energy consumption, with blue color depicting medium energy consumption and red depicting high energy consumption.

Also, from the visualizations, we can see that GenOpt performs only an optimal number of simulations to find the most energy efficient configuration and the solutions begin to cluster around the local minima. The energy ranges from 12,841 kWh to 21,044 kWh in the graph showing the results of parametric simulations, performed only on specific values of variable parameters as shown in Figure 3. Hence, this gives a broader spectrum of energy consumed by the building, as compared to performing optimized simulations, in which energy ranges from 12,920 kWh to 18,093 kWh. We can also see that the minimum energy found by performing an optimized number of simulations using GenOpt is very close to the minimum energy obtained by performing parametric simulations on specified inputs.

Also, from Figure 4, it is seen that, as the WWR increases, the clustering in the lower right corner increases. This shows that with increasing WWR, the energy consumption of the building also increases. This observation is in accordance with what one would expect of energy consumption in hot areas. Therefore, using the visualization presented in Figure 4, we can analyze the clustering in the energy consumption statistics of the building.

CONCLUSION

WinOpt optimizes the design parameters of the windows for minimal operational energy consumption of a conditioned building. It helps in reducing the total number of simulations to be performed and also has visualization tools embedded within it for easier and faster analysis. This tool can therefore be useful in reducing the time and cost for the early stage design.

From the case study, it was found that the total number of simulations performed by WinOpt was 311. However, if each and every possibility has been simulated individually, the simulation count would have been 246,848 (19 x 7 x 29 x 16 x 4). Here 19 different values of azimuth, 7 different values of WWR, 29 different values of Overhang Depth, 16 different values of Aspect Ratio, and 4 different values of Glass Type are considered. The 311 simulations are then only 0.12% of the total possible simulations.

The parametric option in WinOpt is helpful for the users to understand the spectrum of design solutions. With the help of different visualizations that the tool provides, the users can get useful insights about the energy consumed by the building, which can help them in making rapid design decisions for their buildings.

Since the backend of WinOpt uses EnergyPlus as an engine for simulations, the tool could be modified to support simulation for free running / naturally ventilated buildings by evaluating thermal comfort conditions instead of the energy consumption of the building; WinOpt could then also help in design decisions for low energy/ net zero energy buildings.

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The Four Sustainable Design Perspectives

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ABSTRACT

This paper, illustrated with built examples, uses Integral Theory to map four distinct yet ever-present perspectives on Sustainable Design, each with fundamentally different methods, criteria for value, and definitions of good form. The perspectives are articulated by intersecting two primary distinctions: 1) subjective (interior) vs. objective (exterior) ways of knowing and 2) perspectives of individuals (parts, persons, members) vs. collective systems (wholes, networks, societies). This yields four different viewpoints: Behaviours (singular-objective) [the "IT" prospects], Systems (collective/inter-objective) [the "ITS" prospects], Experiences (singular-subjective) [the "I" prospects], and Cultures (collective/inter-subjective) [the "We" prospects]. From each of these varied perspectives on design, the nature of Sustainable Design and that of Nature itself show up quite differently. Yet many Sustainable Design approaches are primarily grounded in the singular-objective Behaviours Perspective. The expanded multi-perspectival view presented here can enable designers to more comprehensively address the complexity of today's ecological challenges by including the individual, cultural and social dimensions that contribute to the creation of a sustainable world.

Keywords: integral theory, performance, systems, cultures, experiences, sustainability

1 INTRODUCTION

Perhaps because of the dominance of empirically-based sustainability perspectives, and the culturally predisposed listening that many of us have for it, designers commonly equate sustainability with technology and sustainable technology with quantifiable energy efficiency or its visible hardware, such as photovoltaic collectors. While Sustainable Design is increasingly associated with performance measures, the wider profession is, on the other hand, increasingly ideologically pluralistic. Despite this pluralism, the design fields, and Sustainable Design in particular, seem to have *no collective framework* for navigating and transcending the fragmentation that entrenches both academia and practice.

Subjective perspectives are missing from most Sustainable Design thinking. As an example, in the US, there are no LEED credits for creating experiences of beauty, none for creating or fitting to ecological order and none for placing people into rich symbolic relationships with Nature. Quality and subjectivity do not appear on this horizon. This is not to argue for devaluing this approach: the technological view of Sustainable Design has done great things for our awareness of the limits of resources and environmental sinks—and the relationships of building design to these.

Similarly, environmentalism based on scientific rationalism has not been very effective. The message goes something like this: 'Look, we have the facts … the sky is falling, we're running out of everything you need, the climate is going crazy and Nobel laureate Al Gore (former US Vice-President) has pictures of the polar caps that should scare the pants off of all of us.' Well, if that does not work to get our collective profession in action, statistics about the contribution of buildings to landfill waste, water consumption and CO_2 production probably will not work too well with a broad audience either—that is, when that's the *only* argument we are making. To address these issues, this paper expands on the

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theoretical views introduced in *Integral Sustainable Design* [1, 2] which was the first work to apply Integral Theory [3, 4] to design, and in particular to the field of Sustainable Design.

2 INTEGRAL THEORY'S FOUR PERSPECTIVES

Integral Theory is an emerging theory base that the author has found to be helpful in teaching and thinking about the complexity of Sustainable Design. An integral theory begins with the assumption that everyone is right—at least partially—and seeks to fashion an intellectual framework that both transcends and includes differences. An integrally-informed approach to Sustainable Design (or anything else) challenges us to hold *multiple simultaneous perspectives* and to address different levels of awareness across the spectrum of human development. Integral Theory is a model that could help design educators and practitioners reconsider the scope, breadth, and multifaceted aspects of sustainability. Integral Theory, as developed by the philosopher Ken Wilber, is based on a cross-cultural comparison of human knowledge, experience, and inquiry [3, 4].

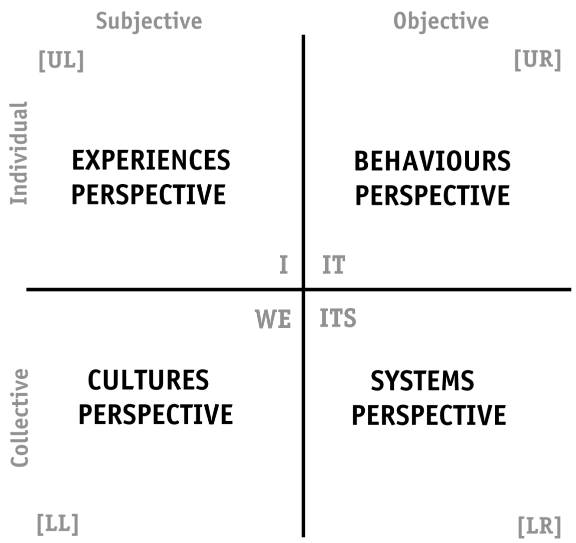

Figure 1 *The four quadrants of Integral Theory*

This paper is limited to the study of one of the most fundamental aspects of the integral model: *quadrants.* At its most essential level, Integral Theory organizes variables for any problem into a matrix of *quadrants* that intersect individual and collective phenomena with objective and subjective knowledge. These combined variables reveal the following considerations (See Fig. 1): 1) *Experiences:* self and consciousness; 2) *Behaviors:* science, mechanics and performance, 3) *Cultures:* meaning, worldviews, and symbolism, and 4) *Systems:* social and natural ecologies and contexts.

The four quadrants are not separate phenomena, but rather four simultaneous perspectives on any event. For this reason, this paper uses the term *perspectives* in place of *quadrants.* Each quadrant or dimension of reality is ever-present and co-arises with the others. The philosopher Michael Zimmerman notes that "The quadrant perspectives correspond generally to the four ways in which universities divide research methodologies (that is, truth-claim generating practices or paradigms): fine arts (UL), humanities (LL), natural sciences (UR), and social and systemic natural sciences (LR)" [5].

Often the two right-hand quadrants, both objective, are considered together, yielding *three value spheres,* associated with *Self* (UL), *Culture* (LL) and *Nature* (UR/LR), or alternatively, *Art, Morals,* and *Science*. Wilber refers to these as "The Big Three," noting that each domain can be associated with the fundamental language distinctions of I, WE, and IT/ITS, or first, second and third person perspectives. This indicates that the perspectives are not opinions or speculative theory, but rather, are so fundamental as to be embedded in all natural languages. The Big Three are the classic value domains of *Beauty, Goodness* and *Truth*. The point is that every event in the manifest world has all three (or four) of those dimensions. You can look at any event from the point of view of the 'I' (how I personally see and feel about the event); from the point of view of the 'we' (how not just I but others see and understand the event); and as an 'it' (the objective facts of the event) [6]. The four fundamental perspectives on any occasion (or the four basic ways of looking at anything), turn out to be fairly simple: they are the *inside* and the *outside* of the *individual* and the *collective* [6].

3 THE FOUR INTEGRAL SUSTAINABLE DESIGN PERSPECTIVES

Figure 2 shows 'The four Sustainable Design perspectives.' The proposition is that each type of perspective is ever-present in all languages and cultures; each both discloses and occludes certain phenomena. *An Integral approach to design is one that unites the beautiful, the art of design, and the good, the ethics of design, with the true, the science of design.* We can also think of design as having four primary dimensions (the four perspectives of the quadrants), each requiring different perspectives on the practice and products of design:

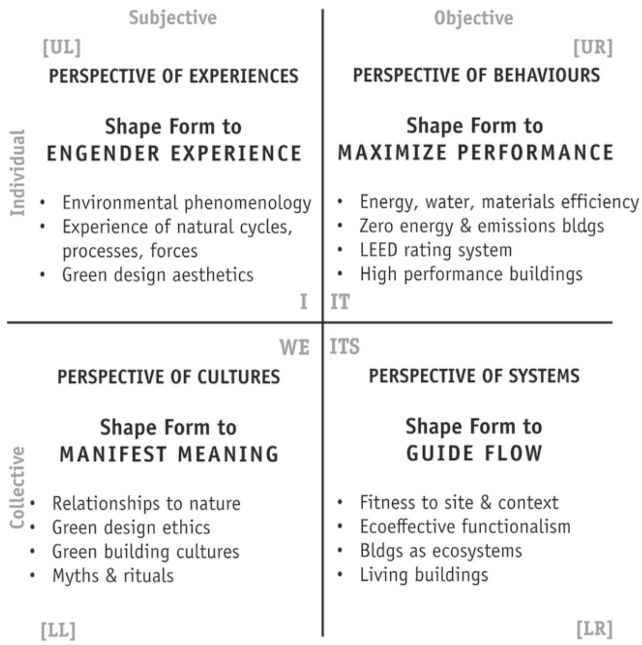

Figure 2: *The four Sustainable Design Perspectives*

Behaviours Perspective: individual parts or members with their performance characteristics, activities, and functions;

Systems Perspective: patterns of forms and flows of energy, information, people, and materials that order ecological and social relationships;

Experiences Perspective: systemic members (human and non-human) with various forms of perception, sentience, and awareness;

Cultures Perspective: shared meaning and understanding at various levels of complexity arising from individual members interacting with each other.

Applied to the consideration of Sustainable Design, the framework reveals that much of the current dialogue takes the Perspective of Behaviours [UR] and is concerned primarily with performance that can be 'measured and weighed,' an important, yet partial view. The Perspective of Systems [LR] reveals that eco-efficiency is not enough by itself to create healthy ecological pattern, and that a logic of 'systems and relationships' can be used to organize the UR logic of 'parts and performance,' either of which *can* constitute a reduction to 'flatland' (Fig. 3). High-performance design collapses everything to the upper right quadrant. Green, ecological approaches collapse reality to the lower right quadrant, or to the right side of the four-quadrant matrix (the web-of-life). Wilber calls this *subtle reductionism* as contrasted with the *gross reductionism* of the upper right. It may be that paying more attention to the perspectives of Experiences [UL] and Cultures [LL] has the potential to vastly expand the effectiveness of the objective arguments for 'design with nature.' Objective, mental arguments often fall on deaf ears for people oriented primarily with values from the subjective (what it feels like to me) and the inter-subjective (what is means to us) perspectives.

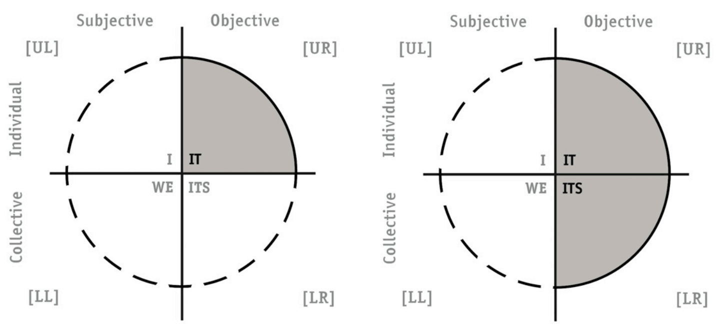

Figure 3 *Gross (left) and subtle (right) reductionism*

4 INTENTIONS AND CRITERIA FOR GOOD FORM FROM THE FOUR PERSPECTIVES

Architectural design is a discipline that requires the shaping of form; in the end, something is built or it is not a building. We can then ask the following questions: 1) *Thinking as designers, how shall we shape* *form for sustainability from each perspective?* and, 2) *From each quadratic perspective, what is the designer's intention and what are the criteria for good form relative to sustainability?*

From the Behaviours Perspective [UR] the design question is: *How shall we shape form to maximize (eco)performance?* Good form minimizes resource consumption and pollution while maximizing preservation and recycling.

From the Systems Perspective [LR] the design question is: *How shall we shape form to guide ecological flows?* Good form solves for ecological pattern by creating structure in the built environment that best accommodates ecological processes through mimicry of and fitness to the context of natural ecosystems.

From the Cultures Perspective [LL] the design question is: *How shall we shape form to manifest the meanings of ecological systems and our relationships to them?* Good form reveals and expresses 'the patterns that connect' in ways that celebrate the beauty of natural order, place inhabitants into relationships with living systems (or their idea of Nature) and situate human habitation in bioregional place.

From the Experiences Perspective [UL] the design question is: *How shall we shape form to engender experiences of Nature and process?* Good form orchestrates rich human experiences of Nature and its phenomena and creates centring places conducive to self-aware transformation to higher levels of (ecological) consciousness.

5 NEW PRINCIPLES FOR INTEGRAL SUSTAINABLE DESIGN

Given the heterogeneous ideas of Sustainable Design, the following illustrative principles have been defined in Figure 4 for each perspective. A *principle* is a statement of the fundamental basis of something, a truth or proposition, as an injunction, that makes ideas portable. Principles serve as the basis of a system of belief or reasoning, and they can be applied across a range of situations. There could be more or less than those given. The principles below follow as articulations of what can be called "an Overarching Principle of Integral Sustainable Design": *Design for sustainability by considering multiple levels of developing complexity in the intersecting domains of self, culture and Nature.*

Experiences perspective [UL]	• *Design profound aesthetic experiences* of natural processes and a living world, accessing multiple senses. • *Design to access human psychological connections to place,* at multiple levels from archetypes to the Transpersonal. • *Design centring places conducive to self-aware transformation* to higher levels of Nature consciousness.
Behaviours perspective [UR]	• *Design high-performance buildings* that maximize efficient use of water, energy and material resources while minimizing waste and pollution. • *Design with on-site renewable resources* of sun, wind and light. • *Design to create safe, healthy places with long-term value*, eliminating toxicity to present or future generations.
Systems perspective [LR]	• *Design at three levels of holarchy*: to build a larger whole, to create a whole and to organize smaller wholes. • *Design living systems using ecology as the model*. Fit flows to local renewable systems while also supporting techno-industrial ecosystems. • *Design solutions fit to particular places,* considered as local site, larger neighbourhood and region.
Cultures perspective [LL]	• *Design based on a high and conscious environmental ethic* in which humanity and Nature both thrive in regenerative human ecosystems. • *Design to place people into significant relationships with Nature* by making visible how culture is interconnected with living systems. • *Design for cultural communication by using the symbolic languages of design* to make evident the meaning of ecological systems.

Figure 4 *Design principles from the four perspectives*

6 THINKING AND BUILDING FROM THE FOUR PERSPECTIVES

Each of the four foundational perspectives require a different way of thinking. These distinctions in thinking yield different concerns for Sustainable Design and a different sustainable architecture. They can also be combined. At an Integral level of complexity, a design might consciously employ all four.

6.1 Thinking and Building from the Behaviours Perspective

The Behaviours Perspective employs an analytic logic of parts and performance that allows designers to dissect projects, measure performance and assess results. It assures efficiency of the constituent building parts. We understand the order of the whole in terms of our *knowledge of individual elements.* It is the most clear and certain way of design thinking. Behaviours Perspective methods depend on observation and on what can be derived from observation. They require us to look scientifically and objectively at observable phenomena, the behaviours of things and people and at the relationships that are seen and quantifiable. Out of this measuring of things one arrives at high-performance buildings as a goal. Its logical extension is plus-energy buildings, zero-emissions buildings, and so on. This perspective reveals that we are running out of many resources and polluting at rates faster than Nature can absorb. It implies a shift from finite to renewable resources. It’s also the perception that takes our vital signs and the planet’s and researches what is healthful and what is not. Thus, in addition to net-zero resource use, infinite recycling and the transition to design with renewables, it promotes a non-toxic environment. Who can argue with that?

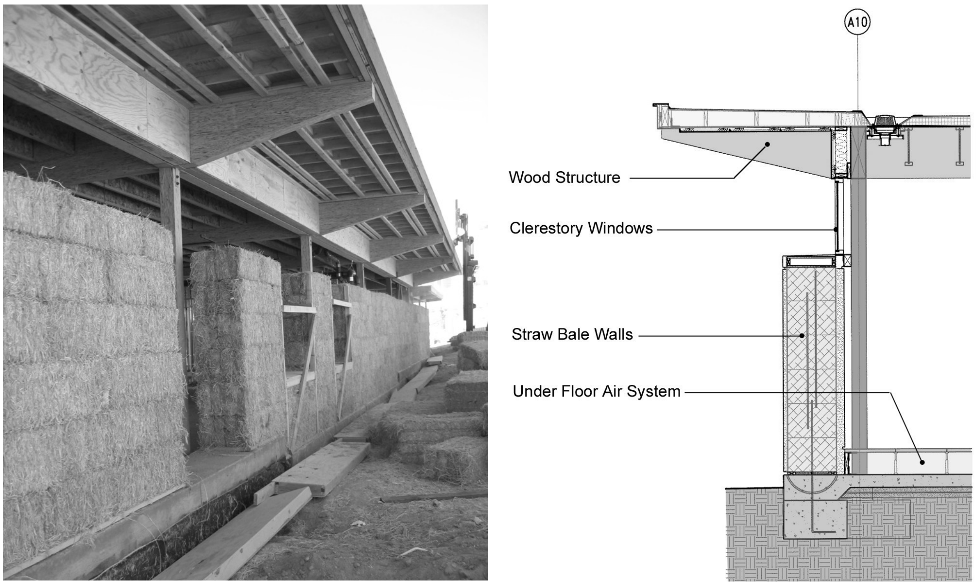

Figure 5 *Santa Clarita transit maintenance facility, Santa Clarita, California, 2008; © HOK*

The first LEED Gold certified straw bale building (Fig. 5), this super-insulated building utilizes photovoltaics to provide half of the operational energy needed and reacts automatically to changing climatic conditions of its desert climate. It uses under-floor air distribution and high-performance glazing. The combination of high- and low-tech solutions helps this building to exceed stringent California energy efficiency standards by 40 per cent.

6.2 Thinking and Building from the Systems Perspective

The Systems Perspective uses a logic of systems and relationships. It is concerned with finding patterns as a basis for making effective design decisions. It is an associative logic that allows designers to see relationships between facts, forces, processes and form. Whereas the Behaviours Perspective tends toward thinking about the ‘application of technology’ and uses quantity as the criteria for success, this perspective embeds technology in architectural patterns, fitting design to its contexts. The Systems Perspective is inter-objective, a third person perspective on social and natural systems. Integration is its most prized value.

In buildings, energy-efficient elements can be combined in intelligent ways to make buildings as energy systems. An example is a passive solar-heated building that can be combined with efficient envelopes and with spatial organizations, orientations and materials to collect, store and redistribute solar energy in complex diurnal and seasonal patterns. The systems of the passive solar-heated building can be combined with those of the naturally ventilated and daylighted building systems. These can be integrated with active mechanical systems, on-site green power systems, and so on. These energy systems can be further integrated with spatial systems, with patterns of use and social order, the order of structural, material and construction systems, with hydrologic systems in the building and site, natural habitat on site, larger contextual urban systems, and so on.

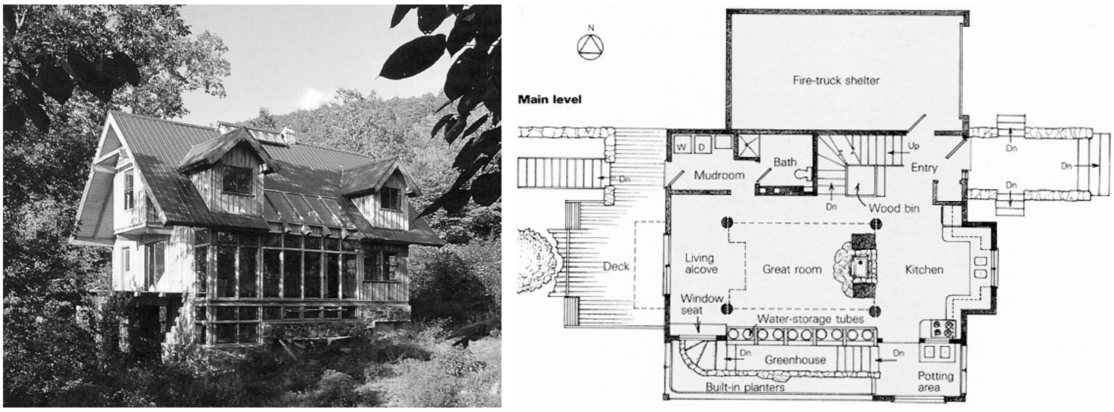

Figure 6 *Solar Farmhouse, Fox, Arkansas, © Gary Coates, with Kansas State architecture students*

In the Solar Farmhouse (Fig. 6), the vernacular dogtrot type meets an atrium and solar greenhouse in a traditional Ozark mountain farmhouse language. The building is organized a series of interrelated design patterns, both social and climatic [7]. The "Dog-Trot Atrium" pattern as a transformation of Alexander's pattern, "Common Areas at the Heart," functions also as a stack-ventilation room and a toplight room. The house is heated by direct gain rooms with solar collection from individual windows and a ridge-top skylight, combined with a substantial two-storey sunspace. Translucent, cylindrical water-filled fiberglass tubes located between the sunspace and the great room serve as thermal mass (and as a food-producing greenhouse), with additional mass in an under-floor rock bed and in the stone walls of the greenhouse stair. The open plan and section allow warm air to rise and enter upper rooms via interior windows, while stratified air is recovered from the top of the atrium and returned to ground level.

6.3 Thinking and Building from the Experiences Perspective

In thinking about the Experiences Perspective, we are concerned with the interior experiences and intentions of designers and with the experiences of the occupants of a sustainable design. For Sustainable Design to be more effective, designers can address the fundamental reality and richness of our human interior experiences. Essentially, if people are to love sustainably designed environments, by necessity designers will have to create loveable places! This means we may choose to design rich full-person experiences, including a range of aesthetic experiences, because responsible action flows most freely from affection, which of itself requires an engaged relationship. A mature Integral Sustainable Design fully engages the human experience of Nature and the subtleties and richness of human feeling in space and place. It is also time for the cultivation of a highly developed theory and practice of Integral Sustainable Design aesthetics that is developmental and multi-perspectival.

To have meaningful discourse about ecological relationships in designed things, individuals must be able to perceive and experience these relationships. Sustainable Design can then ask the design question: *How can important ecological relationships—and the ways design creates relationships to these—be made into significant human-felt experiences?*

Figure 7 *Marie Short House, Kempsey, New South Wales, Australia, 1975, Glenn Murcutt* [8]

Through extensive design for natural ventilation, the Marie Short House (Fig. 7) creates the experience of the process of ventilative cooling. Adjustable steel louvers in the walls control the flow of wind-driven cross-ventilation, while fixed wood louvers allow airflow beneath gables and above open porches. Wide eaves protect from the sun; open plans align space and moving air. And the building communicates the relationship of form to these processes. In its passivity is the occupant's experience of connection to process and place.

> Think of the building as an instrument that's picking up all these sounds..... It's addressing the topography, the wind patterns, light patterns, altitude, latitude, the environment around you, the sun movements. It's addressing the summer, the winter and the seasons in between. It's addressing where the trees are, and where the trees are will tell you about the water table, the soil depth, climatic conditions.' —Glenn Murcutt [9]

6.4 Thinking and Building from the Cultures Perspective

Designers understand that both the *relationships of the natural world* (gravity, climate, energy, ecology, etc.) and *human relationships* (social interactions and human interactions in culture) must be solved for. Seeing Sustainable Design from the Cultures Perspective asks designers to look at how any design places us into relationship with Nature in ways that embody meaning. Anything we design creates or modifies a system of ecological relationships and places humans into an inhabited system in which our relationships to natural forces and processes are tightly bound.

Looking at design from this perspective, designers can ask, *How can Sustainable Design be appropriately ordered to fit its cultural context?* and *How can the patterns of ecological relationships in which the building participates be made culturally significant and appropriate?*

Figure 8 *Shangri La Botanical Gardens and Nature Center, Orange, Texas, 2004, Lake/Flato* [10]

Serving as a place to educate visitors on native ecosystems, the Shangri La Botanical Gardens (Fig. 8) use the surrounding site as part of its regionalist architecture. This LEED Platinum project serves primarily as an interpretive centre for the site's native ecosystems (cypress and tupelo swamp, wooded uplands, and prairie lowlands) as well as a facility for study and research. Nature centres are some of the clearest American expressions of a postmodern Cultures Perspective on Sustainable Design, because they take a clear attitude on what Nature is and tell the story of the human relationship to Nature. While it may perform well, this performance is in service to a cultural ethic.

7 CONCLUSION

A premise of Integral Sustainable Design is that more expansive perspectives on the world are necessary to meet the diverse ecological, social, cultural, ethical, and technological challenges of the twenty-first century. Species interdependence and humans' role in shaping a sustainable future require new approaches that include, yet expand the current emphasis of Sustainable Design on scientific-objective measures. The implication for design is not that each building should address all four perspectives all the time, but rather, that one can be integrally-informed by this expanded view and thus consider, using the tools and methods of that view, each of the four perspectives to question whether or not the issues embedded in the each are relevant for the project at hand.

In addition to designing high-performance buildings and sites, a more Integral view of Sustainable Design incorporates understandings of problems and their solutions that also address the other three important classes of issues.

The highest levels of performance require a systemic approach using method and concepts revealed only from the Systems perspective. Performance in an ecosystem is about dynamically balanced exchanges of energy, information and materials that bring systemic health. Ecological health trumps green efficiency.

The inclusion of a focus on the Experiential Perspective on Sustainable Design fosters the possibility of direct personal knowledge of Nature. Knowledge always precedes care. Care often gives rise to spontaneous action that benefits the object of care. We humans tend to care more about those we know than those we don't know. Having groups of people have experiences of 'Nature-via-design' gives rise to dialogue and interpretation, the key to cultural transformation. Culture in a sense is the effect of all of our conversations. So as designers, can we give people something to talk about?

When Sustainable Design manifests, reflects and expresses ecological processes (from the Cultures Perspective), such as the water cycle for example, it gives people the opportunity to become more aware of living processes and their relationships to them. The stories of our relationships to Nature as told though ecologically expressive built works are powerful. Such expression could allow Sustainable Design to become as transformative of the settled landscape as was post-war suburbia.

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TIMber Buildings with Enhanced Energy and Seismic performance for Mediterranean region: the research project TIMBEEST

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ABSTRACT

How can the summer behaviour of timber buildings be improved without worsening its seismic performance? The research developed by Fraunhofer Italia, Free University of Bozen-Bolzano and supported by Trees and Timber Institute CNR – IVALSA, focuses on passive features of the building envelope. Combining the classifications of the Italian territory based on climate (equivalent Cooling Degrees Days) and structural indicators (horizontal elastic response spectrum), possible improving strategies with thermal mass for different climatic zones are identified. The research considers both building physics and structure implications and matches two structural typologies (Platform Frame and Cross-Laminated Timber) with different building features. The building physics analysis determines some effective building components whose improved cooling energy performances are evaluated by dynamic simulations under the critical period. The structural analysis is aimed at calculating seismic behaviour and limits of a timber structure with applied additional mass loads. The following paper describes the TIMBEEST research methodology by providing work-in-progress results.

INTRODUCTION

The development of architecture features is significantly influenced by the geographical situation. Timber buildings are mostly widespread in cold climates, because of a good thermal performance and the availability of raw material. In fact, the use of timber constructions, especially lightweight walls, is not common in the Italian building stock. The low thermal inertia of timber buildings is identified as one of the main reasons for the worsening of summer thermal behaviour in comparison with clay block or concrete. Hence, it is a limit during the cooling season in hot climates. Passive design of building envelop considers environmental circumstances such as local climate and site conditions, and adopts suitable passive cooling techniques as thermal mass in order to reduce indoor temperature without the use of HVAC systems. Since 1970s, researchers have studied the effect of thermal mass on energy demand and cooling/heating peak loads. Furthermore, the distribution optimization of thermal mass layer and the effective thickness have been investigated. Baverstock demonstrated that the thermal mass effect

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in a commercial building, located in Perth (Australia), decreased the cooling peak loads of 27 %. On the basis of a specific time-dependent method, Shaviv evaluated that the optimum thickness of a concrete thermal mass should be 10 cm for internal partition and 15 cm for external walls. Brown proved that thermal mass applied to walls and floors made possible to achieve cooling demand decrement of 18-20 %. Robertson provided recommendation regarding the best use of thermal mass in residential and small commercial buildings: a 5-10 cm mass wall is usable for daily heat absorption, storage and release, and it is possible to obtain an annual reduction of sensible heating and cooling as high as 40 % for the mild climates. Kosny and Kossecka determined that the distribution of thermal mass on internal side of walls is the best solution for U.S. climates in order to decrease the energy demand. Al-Sanea and Zedan demonstrated that for the arid climate of Riyadh (South Arabia) the thermal mass distribution is optimal when split in two parts by insulation layers, placed at inside, middle, and outside. A previous Fraunhofer research project (Paradisi et al., 2012) regarding the improvement of summer thermal behaviour of timber building investigated and prototyped the technology, which integrates aluminium tubes filled with sand and water on internal side of wall. It has been used in the “Med in Italy House” during the Solar Decathlon Europe 2012 competition, held in Madrid. The thermal assessments, carried out by both dynamic simulation and monitoring campaign, confirm that thermal mass in direct contact with the indoor environmental notably influence thermal comfort and cooling peak loads. TIMBEEST research project aims at understanding the possibility of improving the summer behaviour of timber buildings across the Italian territory by using thermal mass without worsening its seismic performance. This because Italy is a country characterized by an intense and widely spread seismic activity (Civil Protection Department) and high temperature during summer (Pinna, 1978), especially in southern areas. Timber technology presents an excellent structural behaviour in seismic zones, but its low thermal inertia (compared to clay block or concrete buildings) is one of the reasons for worsening the energy performance in cooling period. Since timber technology is rare or even absent in Central and Southern Italy, it is an opportunity to investigate the technological feasibility and effectiveness of timber buildings, considering both thermal performance and structural implications. Three research entities – Fraunhofer Italia for technological development and thermal assessments, Free University of Bozen-Bolzano for dynamic simulation, and Trees and Timber Institute CNR – IVALSA for structural aspects – are trying to answer this question thank to the Autonomous Province of Bolzano-Bozen which supports the research project.

METHODOLOGY

In order to achieve the mentioned goal, the research is structured in three phases as follows:

1. Maps of the Italian territory visualize physical features regarding external restraints such as climate and seismic indicators (equivalent Cooling Degree Days CDD and horizontal elastic response spectrum Se, respectively). The combination of these indicators allows creating a Synthesis Map, which pinpoints the critical areas for timber buildings in terms of summer thermal and seismic behaviour.
2. In order to evaluate energy and structural performances, the most common sample of standard buildings components (walls, roofs, slab/floors) in Platform Frame (PF) and Cross-Laminated-Timber Panels (CLT) with different types of insulation materials is identified. These building components are applied to a reference model, used for dynamic simulations.
3. Based on scientific literature review on thermal mass, on dynamic simulation output data and on linear static analysis, the standard building components are improved. A multi-criteria analysis is developed in order to find out the solution of thermal mass integration in the building envelope which is optimized for 110 capital cities of Italian Provinces. The output data of this phase will be applied to further dynamic and seismic dynamic simulations in order to define the percentage of improvement and its geographical extent, comparing both standard and improved building components.

First phase: Analysis

The first analysis is focused on external restraints regarding energy aspects. In order to achieve a better evaluation of building energy performance, dynamic simulation tools require more complex and detailed inputs such as hourly weather data (Pernigotto et al., 2013). The Test Reference Year TRY as defined by the European technical standard EN ISO 15927-4:2005 is considered as weather data. The TRYs are those provided by CTI – Italian Technical Committee at May 2013. In order to qualify the Italian territory by the high temperatures during summer which can affect the cooling energy demand of buildings, the research team of the Free University of Bolzano-Bozen calculates the equivalent Cooling Degree Days (CDD, [K d]) referred to TRY according to Gasparella et al. (2011). The equivalent CDD, also called Climate Indicator (CI), is calculated for the period from May to September considering: 1) monthly average sol-air temperature ($\theta_{sol\text{-}air,\ \alpha,}$ [°C]) referred to three different horizontal surfaces with absorption coefficient value (α, [-]) respectively 0,3, 0,6 and 0,9; 2) setpoint of cooling temperature (θ_{in}, [°C]) equal to 26 °C. CI indicates the climate characteristic given by temperature and solar radiation of the typical year referred to all Italian capital cities. It is classified in quartiles, as shown in **Table 1** and visualized using QUANTUM GIS software, as shown in **Figure 1a**. The second analysis aims at classifying the Italian territory according to seismic action. Italy is a country characterized by a high seismic activity including areas with low energy earthquakes (e.g. Vesuvius area, Etna area), and areas with seldom earthquakes with higher energy (e.g. Eastern Sicily, Calabria Apennines), as states by the Civil Protection Department. In order to provide a Seismic Indicator (SI), which describes the seismic action on buildings, throughout the Italian territory, the horizontal seismic action on buildings is calculated by the research team from the CNR – IVALSA. To define it, the elastic horizontal ground acceleration response spectrum ($S_e(T)$, [-]) is calculated for 110 capital cities of Italian Provinces according to NTC 2008 and Eurocode 8, assuming the type D of ground classification. **Figure 1b** represents an example of elastic response spectra: x-axis shows the structural period of the building. It is also possible affirm that the fundamental period of timber buildings presented in this study is typically between 0,1 [s] and 0,5 [s]. The calculation of $S_e(T)$ is carried out using Simqke software [12] developed by the University of Brescia. The SI is ranked in five classes according to the SI previously defined, as shown in **Figure 1c** and **Table 2**.

Table 1. Classification of Climate Indicator in Italian territory for different horizontal surfaces

Class	Cooling Degree Days (CDD), α = 0.3	Cooling Degree Days (CDD), α = 0.6	Cooling Degree Days (CDD), α = 0.9
A (light green colour)	< 225 (K d)	< 560 (K d)	< 950 (K d)
B (yellow colour)	225÷290 (K d)	560÷670 (K d)	950÷1100 (K d)
C (orange colour)	290÷360 (K d)	670÷750 (K d)	1100÷1180 (K d)
D (red colour)	> 360 (K d)	> 750 (K d)	> 1180 K d

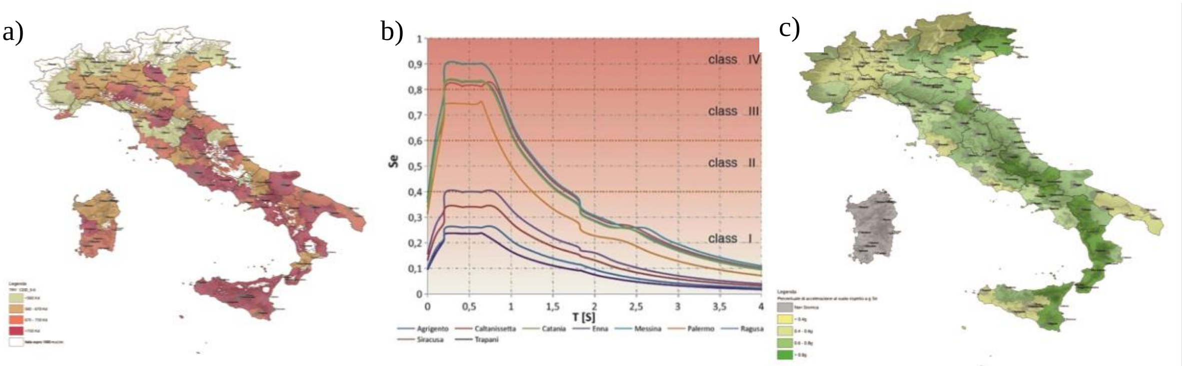


Figure 1 a) Map of CI (α = 0.6); b) Examples of elastic horizontal ground acceleration response spectrum of cities in Sicily; c) Map of SI

Table 2. Classification of Seismic Indicator in Italian territory

Class	Horizontal seismic action ($S_e(T)$)
Non seismic zone (grey colour)	-
I (yellow colour)	< 0.4 (g)
II (light green colour)	0.4÷0.6 (g)
III (green colour)	0.6÷0.8 (g)
IV (dark green colour)	> 0.8 (g)

In order to characterize the territory according to the environmental indicators (EI and SI), which influence the thermal and structural behaviour of buildings, the Synthesis Map using QUANTUM GIS software is created, as shown in **Figure 2**. The Synthesis Map is the result of the overlapping CI and SI maps, identifying nineteen combinations. Each of these maps is referred to the horizontal surface with all three absorption coefficient. Considering the typical use of tiles on roofs, the map with the absorption coefficient value α = 0.6 is the reference for any further evaluation. The Synthesis Map highlights the critical areas, in which contemporary risks of overheating and earthquake occur. This analysis is fundamental for further development of the research, especially for the definition of the improved building components.

Second phase: Energy and structural performance of standard building components

Based on the most common technological solution of timber construction (Benedetti et al., 2010), the research team of Fraunhofer Italia Research individuates samples of standard buildings components (walls, roof, external slab and floors) in two timber technologies – Platform Frame (PF) and Cross-Laminated-Timber Panels (CLT). The dimensions of beams and studs, distance between elements and thickness of panels are calculated by a structural pre-analysis made by CNR-IVALSA according to NTC2008 taking into account the most severe load configuration. The following building components are combined with different types of insulation materials: 1) walls with natural, mineral and synthetic insulation; 2) double-pitch roof with natural, mineral and synthetic insulation; 3) flat roof with synthetic insulation; 4) external slab with synthetic insulation; 5) indoor floors with acoustic insulation. Material characteristics of each layer refer to the database within WUFI software developed by Fraunhofer IBP and UNI 10351:1994. In order to evaluate building thermal performance in the summer period, twenty standard building components have been designed. The evaluated quantities are: 1) thermal transmittance (U-factor, [W m^{-2} K^{-1}]); 2), periodic thermal transmittance (Y_{ie}, [W m^{-2} K^{-1}]); 3) time shift (ϕ, [h]); 4) decrement factor (f, [-]); 5) internal areal heat capacity (k_1, [kJ m^{-2} K^{-1}]); 6) long term thermal capacitance ($d*\rho*c$, [kJ m^{-2} K^{-1}]). Building physics quantities of all components are verified for five climatic zones of the Heating Degree Days (HDD), established by D.P.R. n. 412 26 /08/93 – B, C, D, E, F (zone A in not consider, because no capital city is located there), according to Italian Regulation D.P.R. 59/2009 and UNI EN ISO 13786:2008. The total evaluation of standard building components is equal to 100 combinations.

a) b) c)

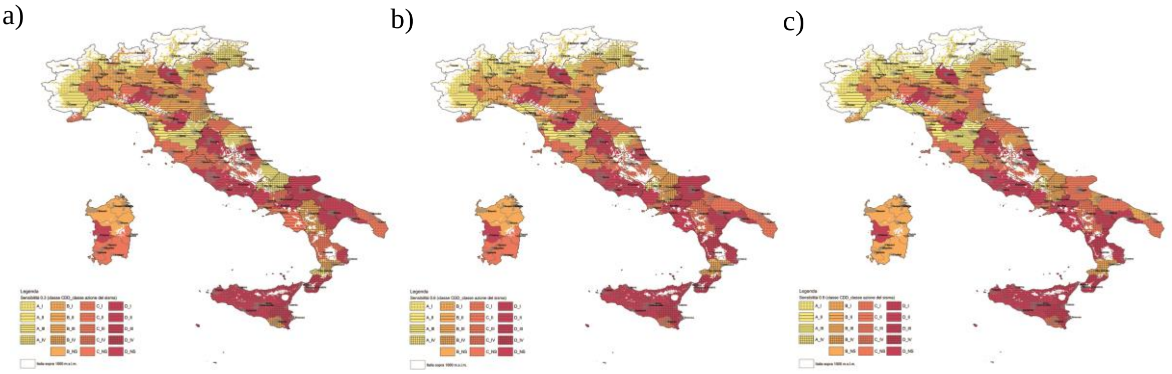


Figure 2 Synthesis Map for surface with: a) α = 0.3; b) α = 0.6; c) α = 0.9.

Based on parameters Y_{ie} and ϕ as assessment criteria, Fraunhofer Italia Research identifies the building components with best and worst summer performance. In all cases the best thermal parameters are registered in walls and double-pitched roofs with natural insulation and in flat roofs with synthetic insulation. The worst thermal performance occurs in building components with synthetic insulation and in case of PF walls with mineral insulation. Synthetic insulation in PF are excluded from the analysis since it is rarely applied. Due to the huge number of calculations, thermal parameters of the best components with lower structural thickness (PF – 8x12 cm; CLT – 10 cm) in climatic zone B are reported only, as shown in **Table 3**.

Table 3. Thermal parameters of standard building components in the Italian climatic zone B (HDD)

Building component	Total thickness [mm]	Insulation thickness [mm]	U-facotr [W m^{-2} K^{-1}]	Y_{12} [W m^{-2} K^{-1}]	ϕ [h]	f [-]	k_1 [kJ m^{-2} K^{-1}]	d*ρ*c [kJ m^{-2} K^{-1}]
WPF_01a	215	150	0.26	0.11	-9.09	0.43	35.68	101.37
WX_01a	225	50	0.41	0.12	-9.29	0.28	33.26	147.97
RPF_01a	155	120	0.29	0.19	-6.50	0.65	38.15	68.19
RPF_02c	215	160	0.23	0.20	-4.08	0.87	35.75	77.65
RX_01c	245	50	0.37	0.06	-11.63	0.17	42.42	212.05
ES	470	60	0.45	-	-	-	46.22	871.70
FPF_01	185	-	0.74	-	-	-	43.33	206.30
FX_02	305	-	0.46	-	-	-	41.28	332.30

These standard building components are combined to a reference model (Pernigotto et al., 2014) with a surface floor of 100 m^2 and 3 m of internal height located in four cities – Messina, Taranto, Firenze, Verona, in order to run dynamic simulations using TRNSYS software. These cities are chosen for two reasons: 1) they belong to D class of equivalent CDD (α = 0.6), being thence under severe summer conditions; 2) they concurrently fall under B, C, D climate zones respectively, which refer to HDD and Italian regulation, and thence consider different winter stress. **Table 4** summarizes the input data used for the dynamic simulations. For each four capital cities Free University of Bolzano-Bozen carries out 34 dynamic simulations (total 256) considering all combinations of input data. The following output data for the period from May to September are given: 1) cooling energy demand (Q, [kWh m^{-2}]); 2) number of days in which the operative temperature (t_o, [°C]) is above 26 °C; 3) number of days in which the operative temperature (t_o, [°C]) is above 28 °C. **Table 5** shows some extract of output data for Messina (HDD zone B) considering the following input data: 1) window surface 25.74 m^2; 2) Solar Heat Gain Coefficient, SHGC = 0.6; 3) Surface Area to Volume ratio, S/V = 0.73 and S/V = 0.4. Simulation results for Messina show that building components with both timber technologies assure already a quite good thermal performance in terms of indoor comfort. The indoor temperature does not reach 28 °C, being almost above 26°C. However, PF building components may have huge improvements, especially in southern areas, where actually the standard technology requires 15 cm of insulation. Traditional massive structure (vertically perforated bricks) requires an insulation thickness of about 4 cm to comply with Italian regulation for the winter season. Therefore, the thermal mass integration in PF structures might decrease notably the insulation thickness. Since CLT components have a massive structure, huge optimization are not required: the thermal mass activation on interior side of wall might be evaluated as an improvement.

Table 4. Simulation input data

Category	Values
Climate input:	
Climate data	TRY (source: *CTI – 05/2013*)
Location	Messina, Taranto, Firenze, Verona
Virtual residential building input:	
S/V ratio	S/V 1: 0.73 (one adiabatic surface – floor) and S/V 2: 0.40 (two adiabatic surfaces – floor and roof)
Dimension of reference case	Volume: 10x10x3 (m)
Building components	- the best and worst configurations of standard components in CLT - the best and worst configurations of standard components in PF
Window position	East, West, South and All without solar shading system
Window surface	Size 1:12.90 m^2 and Size 2: 25.74 m^2
Window characteristics	U_g = 1.2 W/m^2 K; SHGC = 0.6 and U_g = 1.2 W/m^2 K; SHGC = 0.4
Interior gains (W/m^2)	4 W/m² according to UNI/TS 11300
Natural ventilation rate	0.3 vol/h
Interior partition	PF: d = 19 cm; CLT: d = 23 cm (not insulated)
Cooling period	May 1st – September 30th
HVAC system	Ideal system

Table 5. Comparison of best and worst output of thermodynamic simulation for Messina

	Platform Frame				CLT			
	S/V = 0.73		S/V = 0.4		S/V = 0.73		S/V = 0.4	
	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case
Q [kWh m^{-2}]	47.61	47,34	46,02	46,02	51,63	46,42	45,28	44,93
N° of hours > 26 °C	3532	3507	3612	3606	3415	3504	3606	3588

	Platform Frame				CLT			
	S/V = 0.73		S/V = 0.4		S/V = 0.73		S/V = 0.4	
N° of hours > 26 °C	3532	3507	3612	3606	3415	3504	3606	3588
% of hours > 26 °C	96,19%	95,51%	98,37%	98,20%	93,00%	95,42%	98.20%	97,71%
N° of hours > 28 °C	0	0	0	0	0	0	0	0
% of hours > 28 °C	0%	0%	0%	0%	0%	0%	0%	0%

Third phase: Improvement of building components

On the basis of literature review outputs, some technological solutions for Italian climate have been adopted, particularly the one proposed by Al-Sanea and Zedan (2001), which splits thermal mass in two layers. The limit to the mass integration is that it is possible to increase the wall weight up to 1kN per 1m^2 of wall, namely correspond to 20% of the total weight of the considered building model. Such structural constraint comes out of a case study made by CNR-IVALSA. It is a three storey residential building made of two units of the building model described in **Table 4**; 10 [m] x 20 [m] dimension in plan; structural walls and seismic weight are referred to the same building components evaluated with dynamic simulations of the second phase. A linear static analysis is performed according to NTC 2008 and to EC8 in order to define the seismic load and the total base shear force in particular. It is demonstrated the possibility of designing structural walls with increased weight by using standard connectors as hold downs and angular brackets. Taking into account such consideration, Fraunhofer Italia Research designs the improved building components with applied additional thermal mass, as shown in **Figure 3**. The materials considered for the improvement of building components are as follow: 1) double panel of gypsum fibreboard (d = 2x1,5 [cm], ρ = 1800 [kg m^{-3}], λ = 0.32 [W m^{-1} K^{-1}], c = 1200 [J kg^{-1} K^{-1}]); 2) brick (d = 5 [cm], ρ = 1800 [kg m^{-3}], λ = 0.8 [W m^{-1} K^{-1}], c = 850 [J kg^{-1} K^{-1}]); 3) clay panels (d = 2.5-3.5 [cm], ρ = 1600 [kg m^{-3}], λ = 0.73 [W m^{-1} K^{-1}], c = 1000 [J kg^{-1} K^{-1}]). The evaluated solutions for walls are: 1) three types of integration for PF external walls; and 2) four types of integration for CLT external walls. CLT double pitched roof has not been considered as a standard solution because the quantity of timber does not reflect any structural needs. Since it has a better summer thermal performance, CLT double pitched roof is chosen as an improved solution for PF double pitched roof. Due to its better structural behaviour, the indoor floor in CLT technology is preferred to the PF solution. The external concrete slab remains unchanged. The insulation used in all improved walls and roof is a natural one and synthetic one for external concrete slab.

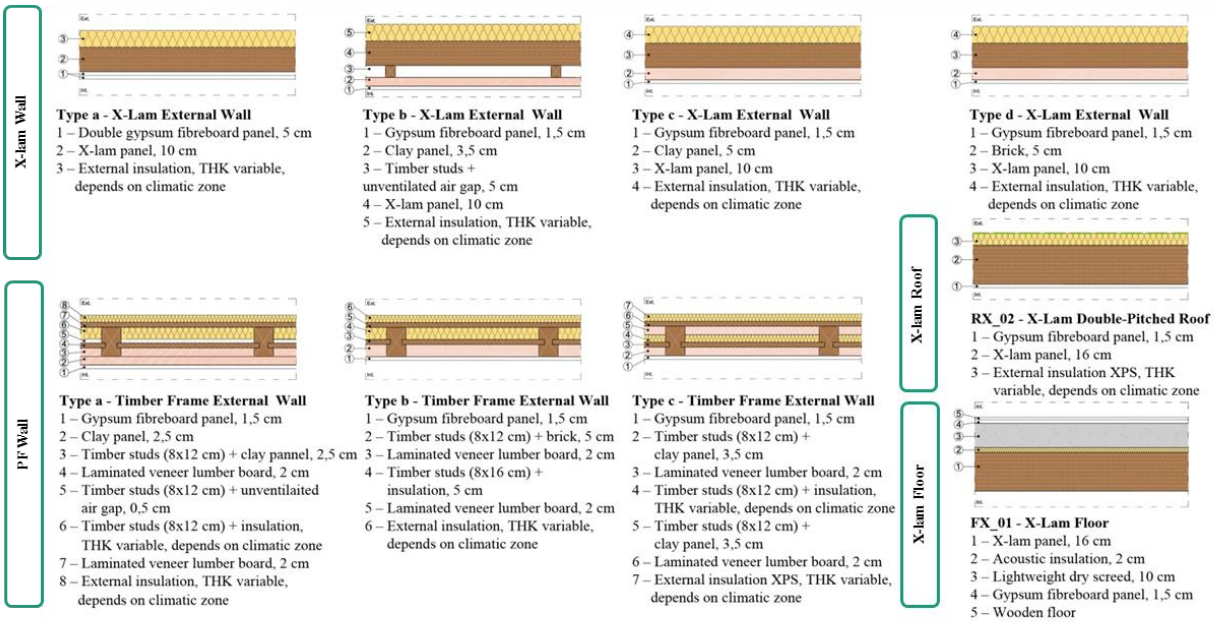
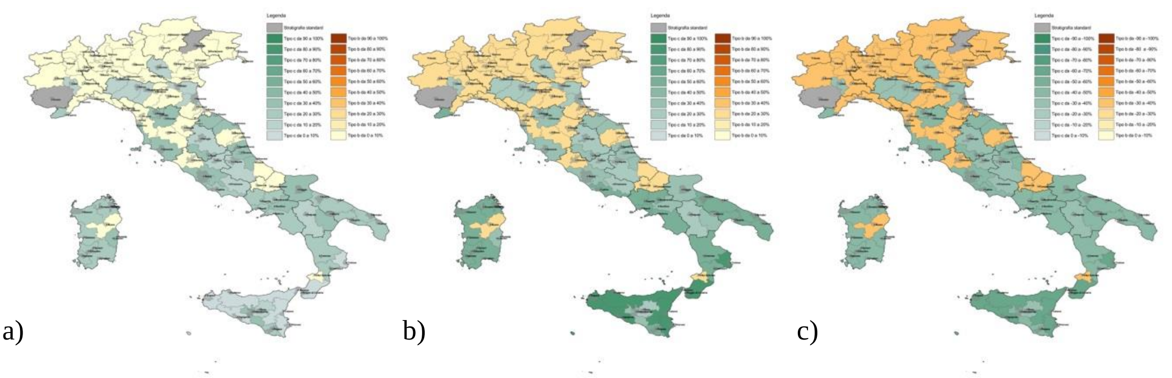


Figure 3 Description of the sample improved building components

In order to find the best solution amongst the proposed improved walls for 110 capital cities, Fraunhofer Italia Research develops a multi-criteria analysis. The three alternatives of integration for PF external walls and the four ones for CLT external walls are compared by four indicators: 1) the average of the percentage difference between Y_{ie} of the improved wall and Y_{ie} of the standard wall with best performance, referred to Y_{ie} of the standard wall with best performance; 2) the percentage difference between U-factor of the improved wall and U-factor of the standard wall with best performance, referred to U-factor of the standard wall with best performance; 3) the percentage difference between total thickness of the improved wall and total thickness of the standard wall with best performance, referred to total thickness of the standard wall with best performance; 4) the percentage difference between insulation thickness of the improved wall and insulation thickness of the standard wall with best performance, referred to insulation thickness of the standard wall with best performance. These four percentage values are weighted by 1-to-3 scale which varies as the combination of climatic zone based on HDD and of class based on equivalent CDD. The multi-criteria analysis supports the selection of the following improved solutions for PF walls:1) type c in areas D, C x B, C, D, E (CDD x HDD) and areas B x C; 2) type b in areas B, A x D, E; and for CLT walls: 1) type d in areas D, C x B, C, D, E and areas B x C; 2) type b in areas B, A x D, E. **Table 6** shows the extract of the multi-criteria analysis referred to class D (CDD) and climatic zone B (HDD) and the selected improved solutions for PF and CLT. GIS-maps of Italy in **Figure 4** represent the percentage improvement or worsening of the indicators which were used for the comparison and selection of the improved building components – insulation thickness, Y_{12}, ϕ, U and total thickness – referred to the chosen improved building components. Thermal parameter values for the chosen improved building components in PF technology referred to class D (CDD) and climatic zone B (HDD) are provided in **Table 7,** while the percentage range of the improvement/worsening of thermal parameters for both technologies are summarized in **Table 8**. There is a huge improvement in terms of decrement of insulation thickness in particular for the PF technology beside an improvement of the thermal parameters which impacts the summer performance.

Table 6. Multi-criteria analysis for CDD class = D and HDD zone = B and selected alternatives

Class D (CDD, α = 0.6)									
Indicators	**PF alternatives**				**CLT alternatives**				
	Weight	**Type a**	**Type b**	**Type c**	**Weight**	**Type a**	**Type b**	**Type c**	**Type d**
Average Y_{ie} and $\Delta\phi$	3	-0.04 (3)	-0.07 (2)	-0.08 (1)	3	-0.33 (4)	-0.69 (1)	-0.54 (2)	-0.49 (3)
U	1	0.43 (2)	0.28 (1)	0.81 (3)	2	-0.04 (1)	-0.04 (1)	0.10 (3)	0.10 (3)
Total thickness	1	0.07 (3)	- (2)	-0.09 (1)	1	0.07 (3)	0.16 (4)	- (1)	- (1)
Insulation thickness	1	-1.40 (2)	-1.00 (3)	-1.80 (1)	3	- (1)	- (1)	- (1)	- (1)
Sum		**-0.94 (2)**	**-0.79 (3)**	**-1.16 (1)**		**-0.30 (4)**	**-0.57 (1)**	**-0.44 (2)**	**-0.39 (3)**



a) b) c)

Figure 4 Comparison maps, the percentage improvement or worsening of thermal parameters: a) Y_{ie} for PF technology; b) U-factor for PF technology; c) Insulation thickness for PF technology.

Table 7. Thermal parameters of the improved building components in the Italian climatic zone B (HDD)

Building component	**Total thickness (mm)**		**Insulation thickness (mm)**		**U-factor (W m^{-2} K^{-1})**		**Y_{12} (W m^{-2} K^{-1})**		**ϕ (h)**		**f (-)**		**k_1 (kJ m^{-2} K^{-1})**		**d*ρ*c (kJ m^{-2} K^{-1})**	
		Δ		Δ		Δ		Δ		Δ		Δ		Δ		Δ
PF Type c	195	9%	60	60%	0.48	-81%	0.11	0%	-9.54	5%	0.24	-45%	55.00	54%	191.71	89%
CLT Type b	260	16%	50	0%	0.40	2%	0.09	26%	-11.14	20%	0.21	25%	52.97	59%	203.97	38%

N.B. Positive value of Δ represents improvement and negative value worsening.

Table 8. The range of percentage improvement/worsening of thermal parameters in Italy

Timber technology	Type of wall	Insulation thickness	Y_{12}	ϕ	U-factor	Total wall thickness
PF	Type b	33%	1%	6%	-28%	No change
	Type c	• 40-60% S*; • 33-40% N*	10-34%	• 5-15% S* • -2% N*	• -29 - -39% N* • -39 - -81% S*	No change or decrement of 9%
CLT	Type b	0%	26%	18-20%	2%	Decrement of 14-16%
	Type d	-14%**	15-27%	15-16%	-4%	Increment of 4%

N.B. Positive value represents improvement and negative value worsening.
* S refers to the Southern Italy; N refers to the Northern Italy; ** increment of insulation only in climatic zone E (HDD)

DISCUSSION AND CONCLUSION

TIMBEEST project has been described as well as its intermediate results. Typical timber building components of the two main technologies (PF and CLT) have been designed and building model performance made out of their combination has been evaluated. Timber buildings have an acceptable performance even in southern Italy but their environmental footprint is high due to the thickness of the required insulation. On the basis of a climate and structural evaluation of the Italian territory, some timber building improved components have been designed. PF walls allow mass to be combined in more solutions than CLT ones as well as mixed technologies better face the seismic challenge. Further steps of the project will simulate and evaluate the percentage of gained improvement in structural and energy fields. It is expected to define the geographical extent of such technology, to determine the environmental footprint of the improved components and to highlight the most promising technological change towards the improvement of timber building performance during the cooling season.

Beyond the limits of the project, it will be interesting to deepen the evaluation of climate indicators as equivalent CDD and to define synthetic indicators combining structure and energy. There are many mixed timber technologies even coming from the past which should be evaluated as PF and CLT as well as the optimization of the mass quantity and position, considering other passive cooling strategies.

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The Triple Bottom Line Benefits of Climate-Responsive Dynamic Façades

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ABSTRACT

To achieve net zero energy, façade designs must move from static dark glass monoliths to dynamic, climate responsive layers for balancing daylighting and shading, natural ventilation and mixed mode conditioning. While 5-15 year energy paybacks are sufficient to prompt some level of increased investment in facades, dynamic facades require the addition of triple bottom line (TBL) calculations that capture the economic, environmental and human benefits of high performance buildings. This paper introduces an approach to TBL justifications of climate-specific high performance building façade solutions, to provide professionals and manufacturers compelling arguments for inspiring building investment that will improve the quality of the indoor environment. Given that lighting and space conditioning are 80% of office energy loads in India, arguments for investing in façades that optimize daylighting and shading, natural ventilation and mixed mode conditioning are critically needed. This paper illustrates the triple bottom line of five climate-responsive façade and related system improvements – high visible transmission/ low solar glass, internal light shelves/inverted blinds, daylight dimming, external overhangs/shades, and operable windows - that demonstrate TBL paybacks of less than two years for new and retrofit construction. This ongoing project is funded by the US Department of Energy and LBNL, and undertaken in collaboration with CEPT, India through the Center for Building Energy Research and Development (CBERD).

INTRODUCTION

The development of TBL life cycle data sets for building decision-makers is critical to overcome first-least-cost decision making patterns that prevent owners and tenants from investing in high performance, energy efficient building solutions. While the completion of five to fifteen year energy payback calculations (first bottom line) can prompt increased investments, the addition of environmental and human benefits (second and third bottom line) provides the 'tipping point' for the level of design, engineering and investment needed for high performance facades that save energy and improve the quality of the indoor environment for workers.

The challenge for TBL calculations is the quantification of environmental and human gains, including health, productivity, and organizational performance. This paper develops TBL justifications for five climate-specific building façade solutions that improve the quality of the indoor environment while optimizing energy effectiveness. For each technology, the first bottom line relates to the known Indian costs and literature identified benefits of energy and facility management savings resulting from the investment. The second bottom line relates to the Indian environmental benefits that are directly linked to electric energy savings: reductions in CO2, SOx, NOx, particulates, and water. The third bottom line is based on available international studies that have identified the human benefits directly

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linked to improved indoor environment quality in terms of human health and productivity.

Carnegie Mellon's studies of daylighting/ lighting retrofits in the U.S., completed for the DOE EEBHub, revealed that with energy savings ranging from 13-85%, simple paybacks will be from 2-8 years - if only energy savings are included in the life cycle calculation. However, when the environmental benefits of electricity savings are included, paybacks are much faster, from 1.5-5 years. Most strikingly, when human benefits identified in international research are included - from reduced headaches and absenteeism to improved task performance or productivity - paybacks for investments in daylighting and lighting retrofits in US offices are less than 2 years (Loftness, Srivastava et al, 2013). Building on these earlier studies, through support from the US Department of Energy and Lawrence Berkeley National Lab, this on-going research advances the TBL evaluation of high performance façade investments for office buildings in each of the five Indian climates identified in the National Building Code.

WHY INVEST IN FACADES?

India is the world's fourth largest energy consumer (EIA, 2013) and fifth largest source of greenhouse gas emissions (GOI, 2010). With the building sector contributing 35% of the total electricity consumption (Rawal et al, 2012), and a projected five-fold growth in the constructed area anticipated by 2030 - from a 21 billion square feet in 2005 to 104 billion square feet, building energy efficiency plays a major role in managing energy use in India (Seth, 2010, Figure 1a).

India's national Energy Conservation Building Code (ECBC, 2008) was revised in 2008, but remains voluntary and has not been adopted by most of the Indian states. To encourage adoption of ECBC, a three-tier approach has been proposed which advocates implementation of the ECBC codes in phases, and allows time for training and capacity building (Rawal et al., 2012). Tiers are categorized based on: ease of implementation within current practice, the energy savings potential, and the ROI offered. Tier one focuses on envelope-related measures, tier two on HVAC, while the third tier regulates lighting measures.

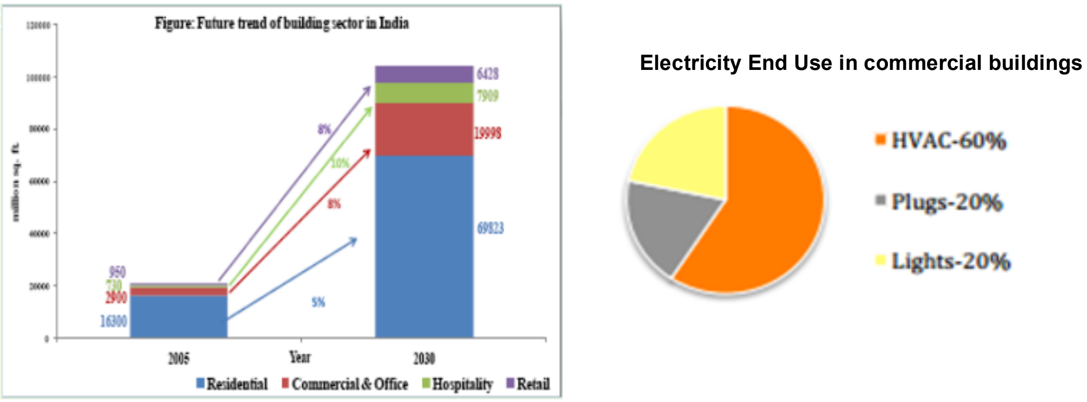


Figure 1 (a)Forecasted five-fold growth for building sector in India; (b) Lighting and Air Conditioning loads account for 80% of the commercial building energy use (Singh et al,2013)

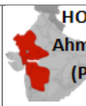
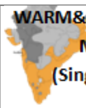
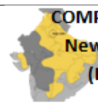
Given the rapid growth in the Indian construction sector, the national government's efforts to improve energy-efficiency in buildings are based on significant reductions in air-conditioning, ventilation, lighting and plug loads. Building façade design and engineering is critical to: air conditioning loads through solar heat control; to natural ventilation and night cooling; to effective daylighting; and even free passive solar heating in cooler climates. High performance, climate responsive facades can significantly reduce both annual and peak electricity demand, and ensure "resiliency" in the face of power outages. Equally critical, high performance facades are critical to occupant health and productivity. This paper explores TBL arguments for five high performance facade measures that can provide up to 25% total energy savings in typical Indian office buildings, reducing the environmental costs of electricity and improving indoor environmental quality for human health and productivity.

Design priorities for new and existing façades

The research team employed a range of techniques to identify climate responsive façade guidelines for Indian climates. A climate analysis using a combination of Koppen climate classifications (Rubel and Kottek, 2010), the National Building Codes (BIS, 2005), Climate Consultant (Milne et al., 2007) and simulation tools (Comfen; NIST Climate Suitability tool; PPG, 2014) supported the identification of representative cities for each of the five Indian climate zones (Table 1) and climatically similar U.S. cities. The companion cities were included to support the development of high performance façade guidelines and provide strong illustrations, quantifications, and product choices. The city of Mumbai was matched with the city of Singapore since there was no climate-comparable city in the US.

The research team then reviewed business-as-usual and advanced Indian office building practices in the five climates, classifying critical characteristics of existing and advanced building facades. Then, the review of existing research, codes and standards, field and simulation studies, was combined with the use of simulation tools to help refine a set of climate specific façade strategies. An illustration of façade design recommendations is shown in Table 1, drawn from a longer list, with 0-3 dots indicating the relative importance of each recommendation for the given climate.

Table 1: Five climatic zones and variations in strategies by climate

Façade Recommendations	 HOT & DRY Ahmedabad (Phoenix)	 WARM&HUMID Mumbai (Singapore)	 TEMPERATE Bangalore (Miami)	 COMPOSITE New Delhi (Dallas)	 COLD Shillong (San Francisco)
Daylighting					
High VLT glass	• • •	• • •	• • •	• • •	• • •
Light shelf/ Inverted blind	• • •	• • •	• • •	• • •	
Daylight dimming	• • •	• • •	• • •	• • •	• • •
Shading					
Shallow Building Plan	• • •	• • •	• • •	• • •	• • •
Avoid E/W Glazing	• • •	• • •	• •	• • •	• •
Low SHGC	• • •	• • •	• •	• • •	
Shading Devices	• • •	• • •	• •	• • •	
Natural Ventilation					
Windows for natural vent.	• •	• • •	• • •	• •	
+ mass for night cooling	• • •	•	• • •	• •	• • •

From the set of shortlisted guidelines in the above table, five strategies were selected to demonstrate the TBL cost benefit analyses that could be applied across all five climates - with climate specific variations:

1. Invest in high visible transmission glass with climate appropriate shading coefficients
2. Invest in light shelves or light redirection louvers in clerestory glass areas
3. Invest in high performance ballasts with daylight sensors in perimeter office lighting
4. Invest in external overhangs or canvas awnings for summer shading
5. Invest in operable windows for natural ventilation and night cooling

Each of the selected recommendations are outlined in the following sections, alongside preliminary information on product or assembly costs, as well as literature studies on occupant health and productivity benefits, in order to complete Triple Bottom Line calculations for each action.

THE TRIPLE BOTTOM LINE FOR FIVE FAÇADE INVESTMENTS

The TBL calculation approach was refined using the United Nations ICLEI Triple Bottom Line Standards, in which benefits are categorized in one of the three categories – (1) Economic/Profit (2) Environmental/Planet (3) Equity/People. The TBL life cycle benefits for each category are illustrated using successive "return on investment" ratios and NPV calculations. For each façade retrofit, the first cost was evaluated against a 15-year life cycle savings calculation. For the range of selected façade technologies, Indian costs were collected from literature and communications with manufacturers and professionals, acknowledging that there are significant variations in the product and labor market across regions. Where the Indian costs for the technologies were not available, the US market prices were used for this paper. The project team collected average technology and labor costs for each recommendation assuming a medium size office of 50,000 square feet on six floors. The energy savings calculations are based on a national baseline of 200 kWh/sqm-yr (approx. 19 kWh/sqft-yr). Load breakdowns are assumed to be: 60% of the total load for HVAC energy use or 120 kWh/sqm-yr; 20% of the total load for lighting energy use or 40 kWh/sqm-yr; with the remaining 20% of energy used for plug loads (Singh et al., 2013). The long-term objective is to build an on-line calculator for building decision-makers to enable the substitution of their own assumptions and numbers.

The first bottom line calculation includes the economic cost benefits of energy and potentially facility management savings resulting from each of the façade actions. The cost of energy was set at \$0.18/kwh, the average all inclusive commercial fixed rate in India (RIL, 2012), which may vary by region (Wilson, 2013). The second bottom line calculations capture the environmental cost benefits that are directly linked to electric energy savings: reduction in CO2, SOx, NOx, particulates (PM) and water demands. These four pollutants are regulated and even taxed in leading countries to reduce global warming, respiratory illnesses, cancers and developmental impairment. Given India's high reliance on coal fired electric power, the societal costs of environmental abatement could range from \$ 0.014 – 0.021/kwh (Table 2), estimated based on EPA (2010), Goodkind and Polasky (2013), Levy (1999) and Ghodke et al. (2012).

Table 2. India's estimated environmental cost impacts of power generation

	CO2	SOx	NOx
India range of emission from coal plant (g/kWh)	783 -1496	5.210 - 9.899	1.612 - 3.490
India Average Emission Coefficients (lb/kWh)	2.18258	0.01907	0.00529
Est. Environmental Cost Premium (/kWh)	**\$0.021**	**\$0.014**	**\$0.016**

The third bottom line captures the human benefits that are linked to improved thermal, lighting and air quality as a result of the building improvement, drawn from the ongoing work of Carnegie Mellon's CBPD to link the quality of the built environment to health and productivity outcomes captured in BIDS: the Building Investment Decision Support Tool (BIDS, 2008). In the absence of Indian field studies that link high performance building systems to health or productivity cost-benefits, the research team relies for now on international laboratory and field case studies to support TBL life cycle decision making.

1. Invest in high visible transmission glass with climate appropriate shading coefficients

20 percent of commercial building energy use in India is for lighting buildings, and much of this is during the daytime when daylight is abundant. Electric lighting also contributes to the air-conditioning demand in Indian office buildings, at a significantly higher cost than solar-controlled daylighting.

Four of the five Indian climates in the codes have cooling dominated seasons, where protection from the sun often becomes a priority. To block solar radiation, use of very dark and reflective glazing is a common practice in Indian buildings. In pursuit of low solar heat gain (low SHGC), designers often mistakenly specify low visible light transmission (VLT). While this type of glazing is effective for shading, it seriously compromises daylight penetration and seated views to the outdoors (Figure 2a). It is imperative for future office facades and façade retrofits to replace yesterday's dark glass (low SHGC and low VLT, see Figure 2a) with today's high performance glass that maintains low solar transmission while maximizing visible light transmission (low SHGC and high VLT, see Figure 2b) in order to lower both lighting and cooling energy while providing views to the outside. Low .30 SHGC with high .65 VLT glass coatings are readily available in India, with incremental costs less than \$1/sqft and paybacks of as low as 39 months (PPG, Saint-Gobain, 2014). For the single heating climate in India represented by Shillong (and companion city San Francisco), the low-solar high-visible glass specification should be replaced by a high-solar high-visible glass specification on southern facades to take advantage of the comfort and free heat provided by direct solar gain.

Figure 2: (a) Use of dark glass in I ICICI Bank in Mumbai specified to reduce solar heat gain vs. (b) Shading while ensuring daylight and seated views to the outdoors (Miami vitHouse, 2010)

The CMU team used existing research to calculate the first, second and third bottom lines of high performance glass. In a 1999 multiple building study of 8 office buildings in the UK, the Probe team identifies an average 64% lighting energy savings in buildings with effective daylighting due to clear glass and perimeter access, as compared to buildings with deep floor plans and/or tinted glass (Probe team, 1999). Increasing the effectiveness of daylighting and providing access to views also improves employee productivity and health, also included in the third bottom line. In a 2003 building case study of the Sacramento Municipal Utility District (SMUD) Call Center, Heschong et al. identified an average 6.7% faster Average Handling Time (AHT) for employees with seated access to larger windows and a view with vegetation content from their cubicles, as compared to employees with no view of the outdoors. Other studies reveal the importance of sunshine for health in winter with appropriate orientation and shading for glare control and summer comfort (Benedetti et al., 2001 and Choi, 2005).

2. Invest in light shelves or light redirection louvers in clerestory glass areas

To ensure daylight effectiveness beyond the first few feet of work area, the second retrofit recommendation is to introduce light shelves or inverted blinds/louvers in the clerestory glass area. Light shelves serve critical purposes that include the distribution of daylight deep into the building, glare control and shading. When well designed, they can ensure high levels of daylighting without glare and overheating, and even reduce heat loss on winter nights (CBPD, 2014 a). A study of the existing building stock revealed that a number of Indian offices already have clerestory glass above the view windows (Figure 3a), and the addition of a light shelf or inverted louvers or blinds will greatly enhance daylight effectiveness.

The ideal light shelves would be highly reflective and diffusing. If louvers or venetian blinds are used they should be inverted (curve upwards) to reflect daylight onto the ceiling for diffusion (see Lightlouver™ profile Figure 3b). The inverted blinds can even have a seasonally "smart" W-profile that reflects high sun angles back outdoors, to reduce solar gain in the cooling season, and reflects low sun angles into the space to increase solar gain in the heating season (Retrosolar™). Inverted blinds and louvers in the clerestory, in combination with a highly reflective ceiling, create a daylighting system that can be used on the east, west and the south façade. The most affordable solution for the Indian market is approximately \$20 per sqft of building façade, based on manufacturer estimates, given 20% of the baseline building surface area as clerestory to be equipped with light shelves (Skyshade™, 2014).

Figure 3: (a) Typical Indian office with no daylight redirection device (b)LightLouver units in clerestory to reflect sunlight into the ceiling

Given that 25-100% of workstations may be within 15 feet of a window wall in many Indian office buildings, daylighting without glare can save up to 35% of a medium size office building's total lighting energy (Figueiro et al., 2002; Schrum & Parker, 1996). The electricity savings is calculated in the first bottom line and the environmental benefits of reduced power generation is calculated in the second bottom line.

The human benefits of investing in light redirection/diffusion are related to the spectral quality of daylight, the management of brightness contrast by bouncing light, the improvement of views, as well as the importance of sunshine in winter and shading for comfort in summer. For example, in a 1992 laboratory experiment conducted using 26 subjects, Osterhaus and Bailey found a 3% improvement in visual tasks related to reduced glare (Osterhaus & Bailey, 1992).

3. Invest in high performance ballasts with daylight sensors for perimeter office lighting

The third cost-effective retrofit is the use of high performance ballasts and daylight sensors to support on/off or dimming control of the first and second rows of lights on each building façade (Figure 4a). This investment in new controls for groups of lights ensures up to 30% energy savings through 'daylight harvesting'(Lee & Selkowitz,2006). In a 1984 simulation study supported by meta-analysis, Verderber and Rubinstein identify 64% lighting energy savings in a 30% daylit building given daylight dimming controls, automatic scheduling, tuning, and lamp lumen depreciation, compared to a conventional lighting system with no controls. To ensure that the sensors are not disabled or covered by occupants, critical attributes for the selection of daylight sensors include: programmable thresholds for acceptable daylight minimums, relocatable sensors to address variations in office layout, and assurance of gradual light level changes through dimming or time limited switching. Daylight sensors and switches can be installed without full automation systems, and can be introduced with wireless interfaces to existing fixtures, making them cost effective retrofits.

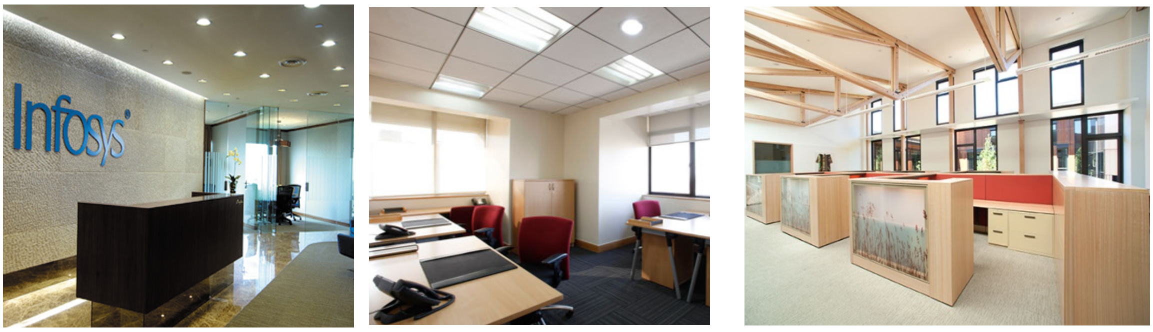


Figure 4: a, b) Electric lighting 'on' most of the time in Infosys and Raheja Tower offices in Bangalore; c) Balanced daylight and daylight harvesting controls in the Packard Foundation offices in California.

Encelium, Lutron, and several other lighting control companies have developed wireless controls that can be added to existing ballasts in combination with well-placed daylight sensors. A web based controller is available for calendar-driven or daylight-sensor-driven switching of each row. Daylight harvesting is a quick and low cost retrofit for the majority of buildings, with costs from \$0.45- 0.90/sqft.

In many medium sized office buildings, up to 100% of spaces could be (and have been historically) daylit, saving up to 70% of total lighting energy. In deeper section buildings, daylight harvesting can save 10-35% of the lighting energy. The human benefits of daylight contributions in the workspace are also measurable. In a 1995 building case study of Lockheed Building 157 in Sunnyvale, California, Thayer et al identified 50% savings in lighting, cooling and ventilation energy and 15% reduced absenteeism due to the daylighting design which integrates layout, orientation, type of glazing, and light shelves in combination with reflective ceilings. The full spectrum light inherent in daylight also has an influence on human health, with research revealing that the natural changes in day light is critical for melatonin production that regulates our sleep cycle (Figueiro, 2010). An earlier field study conducted by Figueiro et al. (2002) identifies a 15% increase in time dedicated to visual tasks in daylit workspaces. With visual tasks constituting 25-30% of time spent at work, there is a potential performance improvement of 3.75% linked to the benefits of daylight. Daylighting should be a priority in the workplace, particularly since higher light levels can be achieved at a lower energy cost.

4. Invest in external overhangs or canvas awnings for summer shading

In four of the five climates of India, shading the facade is a high priority to avoid overheating in summer. While modern office buildings in the past century were often sleek glass towers, today's design community is rediscovering the power of facades articulated by static fins, louvers, and screens as well as the highest performing dynamic awnings. These dynamic shading devices can be daily or seasonally adjusted to reflect sunlight when required, while allowing effective daylight penetration and solar gain during the winter (Lechner, 2009). Today, awnings are made of synthetic fabrics which are fade resistant, water repellant and require less maintenance than they have historically. Fixed overhangs, horizontal louvers and fins, and dynamic awnings are each effective additions to modern facades. They provide shade with daylight, without diminishing our views, and should replace yesterday's dark glass, eggcrate shades and scrim layers.

Given that India ranges from 6^{o} to 37^{o} north latitude, horizontal devices should be the norm for southern orientations, combined horizontal and vertical or dynamic devices for east west, and vertical devices for north facades (Figure 5b,c). Openings along the top and sides of the overhang or awning should be provided to prevent heat from being trapped at the window wall.

Figure 5: a) DLF Center, Delhi with no shading devices vs. b) vertical awnings on the north face of the Phoenix library, and c) horizontal louvers on south face of Stecalite, Noida.

The cost of installing external louvers and awnings varies dramatically based on material and assembly, with $7.50/sqft assumed in the TBL calculations. The use of adjustable awnings as a shading device can reduce solar heat gain and associated cooling loads in the summer by up to 65% on south-facing windows and 77% on west-facing windows, with a 20-25% total cooling energy savings (DOE, 2012; Nagy et al., 2000). The human benefits of light shelves include the value of glare control for productivity and health, as well as shading for improved thermal comfort in summer by reducing direct and radiant solar heat. In a 1998 controlled experiment, Witterseh identifies a 54% increase in mathematics accuracy and a 3.5% typing improvement when subjects feel thermally comfortable, rather than too warm, in quiet office conditions (Witterseh, 2001).

5. Invest in operable windows for natural ventilation and night cooling

The last recommendation for which triple bottom line analysis was completed was to introduce operable windows for natural ventilation and night cooling. The business-as-usual building illustrated in figure 6a, reveals the rising trend of sealing office facades (Figure 6a). This is a serious disadvantage during brown outs or black outs, as the building runs out of air and starts to overheat. Moreover, sealing building facades eliminates the opportunity to use natural ventilation for cooling and breathing, or night ventilation to pre-cool the building to offer hours of free cooling the next day.

To avoid the possibility of rain coming in, and to ensure controlled air flow, the use of awning, drop-kick, and pop-out windows are emerging in modern offices (Figure 6b and 6c). For hot and dry climates like Ahmedabad, natural ventilation can be pursued on moderate days if air quality and noise are not a local issue. More critically, night ventilation cooling can be pursued on nights that are predicted to be cooler than 70°F and combined with thermal mass or phase change materials to store 'coolth' for conditioning on the following day.

Figure 6: a) Infosys, Bangalore with no operable windows, b) 3i Innfotech EPIP Whitefiled with a modest percent of operable windows, but dark glass c) Deutsche Bank, Frankfurt with high Tvis pop-out windows.

The cost of natural ventilation is related to the additional costs of window hardware and the manual or automated system for control, while night cooling requires the addition or exposure of thermal mass in the airstream. Mechanical engineers should be carefully selected for their commitment to "mixed mode" conditioning (CBE, 2014), and integrated early into the design process. Consideration of natural ventilation should address the site-specific limits of climate, outdoor air quality, noise, security, and local building codes.

On the benefit side of the equation, the annual energy savings of natural ventilation in the climate of Ahmedabad includes up to 15% of ventilation loads (Milne et al., 2007) and up to 35% pre-cooling load (Emmerich, *Climate Suitability Tool*). International studies reveal that the human benefits of natural ventilation can be measured in both employee health and productivity. In a 2003 meta-analysis study, Seppänen et al identifies a productivity increase of 4.9% for an eight-hour workday due to night-time ventilative cooling, an energy-efficient method of reducing daytime indoor temperatures by using night-time air to cool a building's structure and furnishings. In a 1988 multiple building study in Berlin and Heidelberg, Kroeling identifies a 33% reduction in reported headaches, a 28% reduction in reported frequency of colds, and a 31% reduction in reported circulation problems for employees in naturally ventilated office buildings as compared to air conditioned office buildings.

TRIPLE BOTTOM LINE RAPIDLY ACCELERATES PAYBACK FOR DYNAMIC FAÇADES

Given these international studies on the human benefits of high performance façade solutions, the research team completed TBL calculation for five façade investments in the hot and dry Indian climate, to demonstrate the applicability of the framework in the building decision-making process (Table 3). For each facade investment, a 15-year life-cycle calculation is completed with the Indian first costs, energy savings and environmental benefits, and combined with international findings on health and productivity benefits, to generate the triple bottom line results shown in Table 3.

Table 3: TBL calculation for five façade investments

		High VLT Glass	Light Louvers	Dimming Ballasts	Awnings for shade	Operable Windows
Economic Considerations	**First cost per employee**	$45	$114	$70	$330*	$120
	Annual Energy savings:					
	Energy Savings (%)	35%	35%	30%	20%	35%
	Energy savings per employee	$24	$23	$20	$40	$70
	ROI (Economic)	**52%**	**20%**	**28%**	**12%**	**58%**
	Payback in years	**2**	**< 5**	**3.5**	**8**	**< 2**
Environmental Considerations	Given Annual Energy savings in kWh	130	130	113	224	392
	Annual Environmental Benefits:					
	Air pollution emissions (CO2, SOX, NOX = $.051/kwH)	$6.7	$6.7	$5.8	$11.4	$20.0
	Water Savings ($0.002/kwh)	$0.3	$0.3	$0.2	$0.4	$0.8
	ROI (Eco + Env)	**68%**	**26%**	**38%**	**16%**	**76%**
	Payback (Eco + Env) in years	**1.5**	**< 4**	**< 2.5**	**< 6.5**	**< 1.5**
Equity Considerations	**Annual Human Benefits**					
	Productivity increase (1- 4%)	$320	$240	$300	$100	$240
	Reduction in absenteeism (6 -14%)	$24	$24	$24	$24	$10
	ROI (Eco + Env+ Equity)	**825%**	**258%**	**500%**	**52%**	**284%**
	Payback (Eco + Env + Equity) in years	**< 0.5**	**< 1**	**< 0.5**	**2**	**<1**

*Awnings have a lifetime of 5 years; first cost includes prices for three changes

The development of Triple Bottom Line life cycle data sets for building decision-makers is critical to overcoming first-least-cost decision making patterns that prevent owners and tenants from investing in high performance, energy efficient building solutions. For example, the investments in high visible transmission glass with climate appropriate shading coefficients shift from 2 year paybacks based on energy savings alone, to 1.5 years including environmental benefits, to less than 6 months given the human benefits. Investments in the most affordable light redirection louvers in clerestory glass areas, high performance ballasts and daylight sensors, canvas awnings, and controls for operable windows also demonstrate reductions in paybacks from 8 years to less than a year as energy, environmental and human benefits are cumulatively calculated. It is critical for building owners and their design-engineering teams to embrace layered and dynamic facades for daylight, shade, natural ventilation and night cooling to significantly reduce India's lighting and cooling loads in commercial offices and improve indoor environmental quality.

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The *Bundle-Up!* Game: a collaborative learning tool for net-zero energy design

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ABSTRACT

The purpose of the Bundle-Up! game is to make learning climatic design strategies and their complex interrelationships fun and easy. The project uses the concept of Bundles developed in the research project, "A New Knowledge Structure for Net-Zero Design." The idea of design strategy bundles is to resolve conflicts and tensions among strategies by proposing related sets of design strategies that address recurring problems designers face. A Bundle identifies several discreet design ideas that apply in a particular situation across three scales. The game outlines a set of rules for users to create their own bundles specific to a particular project. Bundle-Up! is used with a set of instructions like a typical board game. It is designed to use design strategies from the book Sun, Wind & Light*, 3rd edition. There is no one right solution, but some answers are better than others, and solutions that follow the rules are all acceptable. Bundle-Up! can be played by one person or several in collaboration. The game pieces (more than 100) each represent a climatic design strategy, each with a unique graphic and other identifying features and descriptions. A prototype was tested with peer teachers and feedback was very positive. The Bundle-Up! game has since been tested in fifth-year B. Arch design studios and with second-year technology course students. Feedback has helped refine the game and its instructions, along with the curricular exercises that accompany it.*

Keywords: passive design, design process, knowledge structure, education, design strategies

1 INTRODUCTION: DESIGN STRATEGY BUNDLES

In the U.S., the American Institute of Architects has adopted 'Architecture 2030' goals for all new buildings to be carbon-neutral, operating free of fossil fuels by 2030. Carbon-neutral performance can either be achieved by a wasteful building with huge green power systems and purchase renewable energy or by efficient buildings lighted and conditioned by site-based resources, paired with small on-site green power systems. In other words, passive heating, cooling and lighting strategies reduce net loads, which reduce the need for expensive utility green power, photovoltaics and wind generation. To assist designers with this second more architectural and passive energy approach to carbon-neutral performance, this project uses the concept of *design strategy bundles* developed in the research project, "A New Knowledge Structure for Net-Zero Energy Design" and further developed and published in *Sun, Wind & Light: architectural design strategies,* 3rd edition (*SWL*) [1]. Bundles are theoretically a combination and development of Pattern Language theory and holarchic structure, particularly as developed in Integral Theory. The second edition of *Sun, Wind & Light* included 109 discreet analysis techniques and design strategies across a range of scales. These strategies addressed issues of heating, cooling, lighting and power. The strategy bundle was born in part as a result of finding three challenges that surfaced in over a decade of using the second edition in teaching and consulting:

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1. *Difficulty in knowing which strategies to use* for a particular design situation, such as designing the building envelope, especially for novice passive designers
2. *Challenges identifying how the strategies were related* to each other—or not related—was sometimes implied, but often opaque, and required substantial practical experience
3. *Difficulty in knowing how major variables, like climate type, changed which strategies to employ* or to emphasize.

The purpose of design strategy bundles is to resolve conflicts and tensions among strategies by proposing related sets of strategies across three scales. A bundle proposes a set of the almost-always-required strategies that come together to form solutions to design situations encountered repeatedly in buildings. Some design situations are recurring, such as the problem of how to bring in light through a roof or how to use the building to collect and store heat from the sun in a cold climate.

When one is able to generalize about these design situations, one can also generalize about the solutions and the characteristics of these solutions that seem to be workable across a variety of conditions. If a problem is encountered thousands of times in buildings, the building community develops particular solution types from which designers can learn.

A *Bundle* is defned here as a set of related strategies working together to resolve commonly occurring design problems. A bundle may address a single energy issue or it may address two or more energy topics (heating, cooling, daylighting, ventilation or power). In general, a bundle has the following four characteristic organizing principles, as illustrated in Figure 1:

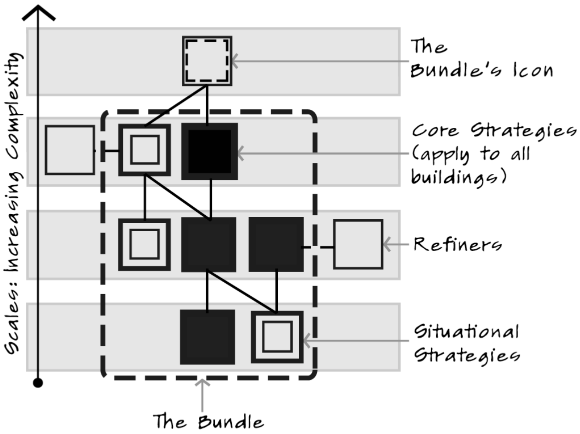


***Figure 1**: The structure of a bundle*

1) *A Bundle covers two or more scales* in the hierarchical system for levels of complexity (*SWL* uses nine scales). Most of the fundamental bundles cover three levels (the gray bars). The black lines connecting the squares represent a particular kind of relationship among the strategies of lower and higher complexity. The levels function to make clear how less complex strategies help to build more complex strategies.

2) *A Bundle has 3–5 invariant core strategies* (the solid black squares) that are always workable in the given design situation. Core strategies are recognized as those that apply to all the bundle's variations.

3) *A Bundle has two or more situational variations*, each with its own bundle diagram. These variations adapt the bundle to a major variable commonly present (such as the difference between designing in a cool climate versus a hot-arid climate) by the addition of situational strategies (the hollow squares inside the dashed line) beyond the core strategies. Remember that core strategies are common to all of the situational variations, whereas situational strategies are more workable or important in one scenario than in the others.

4) *A Bundle may also identify refiner strategies* (the squares outside the dashed line), which are related to the bundle and are recommended to be considered as the design develops to greater levels of detail. These are most likely workable but are less critical strategies.

Because each strategy has a range of variables and can be adapted to variations in its context, the particular combination of strategies suggested for a bundle can yield thousands of formal outcomes. Similarly, the relationship of one strategy to another in a bundle will influence the way in which each strategy is applied. The designer fits one strategy to the others in the network of design strategies that forms the bundle. This network is a context of other more and less complex strategies.

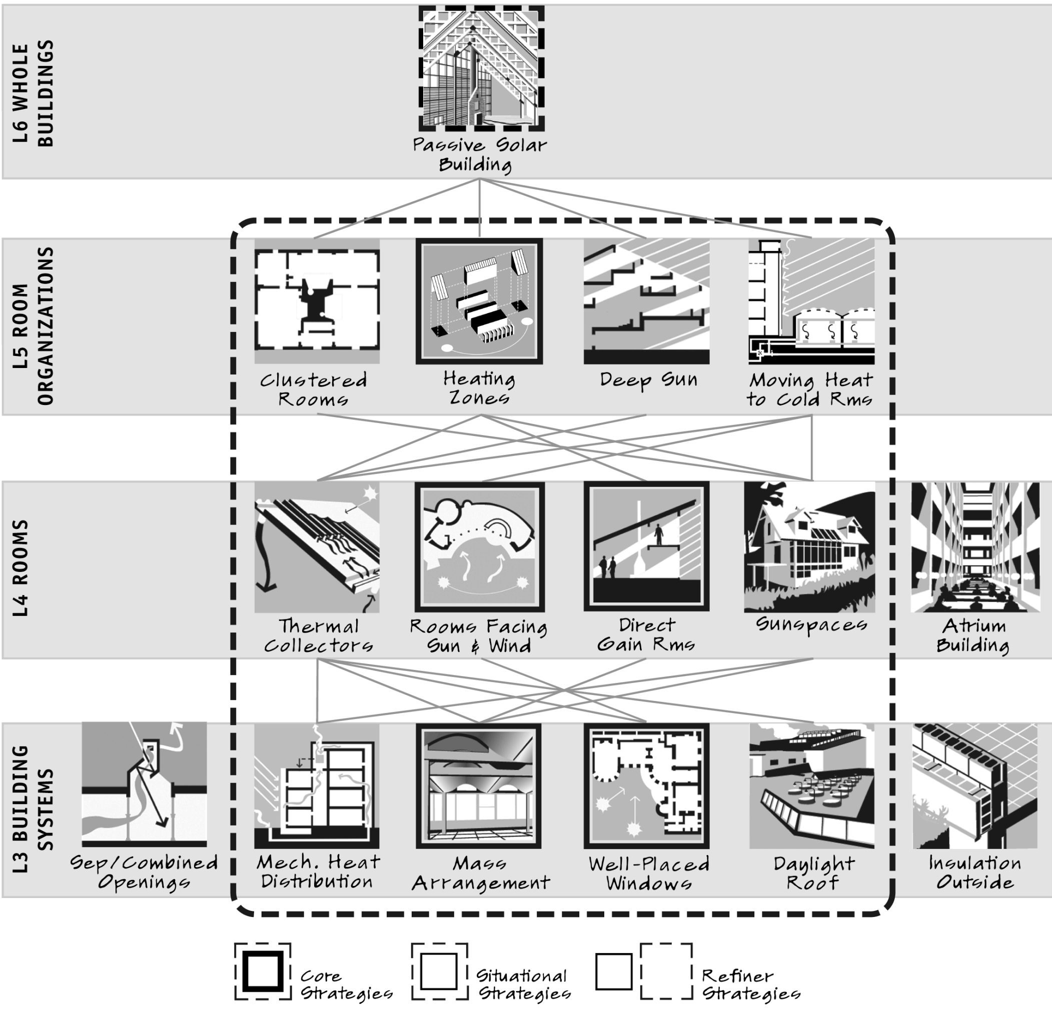


Figure 2: *Passive solar building bundle, thick plan variation*

2. EXAMPLE BUNDLE

The example bundle diagram in Figure 2 for a thick plan PASSIVE SOLAR BUILDING bundle, one of its two variations, illustrates the four organizational principles of a bundle.

1) *The bundle organizes design strategies at multiple scales,* covering three levels of complexity, from lower complexity level three (L3) Building Systems, to L4 Rooms, to higher complexity L5 Room Organizations. These are named in the range of grey bars on the left side of Figure 2. The scale of L6 Whole Buildings is the contextual scale for this bundle and is the level where its particular "emergent characteristics" are evident. The gray lines connecting the squares represent nesting relationships between strategies. For example, the less complex strategies of SUNSPACES, ROOMS FACING THE SUN AND WIND and THERMAL COLLECTORS are all strategies for designing at the L4 Rooms scale; they help to build the more complex strategy MOVING HEAT TO COLD ROOMS, which operates at the more complex scale of L5 Room Organizations to orchestrate heat distribution between rooms that collect heat and those that do not. SUNSPACES helps build MOVING HEAT TO COLD ROOMS, while the higher, deeper, larger strategy also depends on the lower strategy. Bear in mind that the bundles represent some important associations of strategies, and that many additional strategies may be used. Note that, for simplicity, the relationship lines for *refiner* strategies are not shown in the diagrams, but they can be seen on the design strategy maps in *SWL's* chapter on "Navigation by Design Strategy Maps" [1].

2) *The bundle has five core strategies*. Each graphic icon represents an individual design strategy in *SWL*. Core strategies are shown in Figure 2 with a bold outline: HEATING ZONES, ROOMS FACING THE SUN AND WIND, DIRECT GAIN ROOMS, MASS ARRANGEMENT and WELL-PLACED WINDOWS. These will apply to almost all PASSIVE SOLAR BUILDINGS of both Thin Plan and Thick Plan variations.

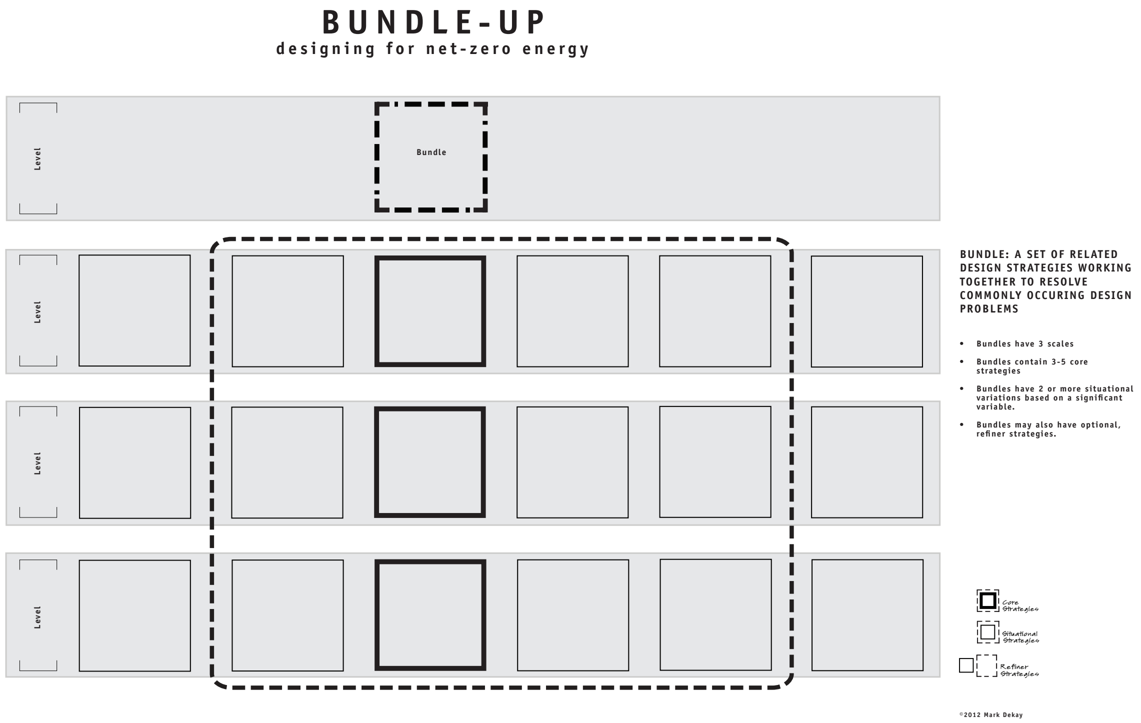


Figure 3: *Bundle-Up! game board*

3) *The bundle has two situational variations,* one for a *thick plan building* (shown in Figure 2), in which a significant portion of rooms do not face the sun, and one for a *thin plan building,* in which access to the sun by each room is easier. The *situational strategies* are located *within* the bundle boundary (bold dashed line); their icons have no border, for example: CLUSTERED ROOMS, SUNSPACES and MECHANICAL HEAT DISTRIBUTION. These design strategies will typically apply to one of the bundle variations, but not to all of the variations. The situational strategies are appropriate almost all of the time, yet not every strategy need be used in every project. For example, most Thick Plan Variation buildings will need MECHANICAL HEAT DISTRIBUTION to move heat from rooms or surfaces that collect solar heat to remote rooms that do not have direct access to solar heat, but a Thin Plan building can usually use passive radiation or local passive convective loops to distribute heat.

4) *Refiner strategies are less critical* to the bundle's success or have less impact on architectural form than core or situational strategies. However, they may still have a large impact on performance in Figure 2. The refiner strategies are located *outside* the bundle boundary (*bold dashed line*) and their icons have no borders: ATRIUM BUILDING, INSULATION OUTSIDE and SEPARATED OR COMBINED OPENINGS. For example, in a thick plan PASSIVE SOLAR BUILDING, a light court may be used in an ATRIUM BUILDING arrangement; the atrium may also double as a SUNSPACE to collect heat if its roof or one wall has SOLAR APERTURES oriented to the sun. This refiner strategy will not apply to all buildings, but if used, could improve the performance the bundle offers.

4 THE *BUNDLE-UP!* GAME

The *Bundle-Up!* game was developed as a fun way to learn about designing with bundles. It allows players to build their own bundles of design strategies that are more specific to their design's program, site, and climate than the more generic "fundamental bundles" in *SWL.* The game board (Figure 3) follows the structure of bundles as described above. Users select "Scale Cards" from among nine options (Figure 4a). Scales must be sequential from smaller to larger. A colored "Bundle Tile" from among nine current options (Figure 4b) is placed in the top position, or, alternatively, a blank tile may be selected and given any original name by players who wish to create a custom bundle for a new problem type. Each fundamental bundle and design strategy (currently 115 total) from *Sun, Wind & Light* [1] is represented by a "Strategy Tile" (Figure 5). The front of the tile shows its *SWL* strategy icon, abstracted

a) 

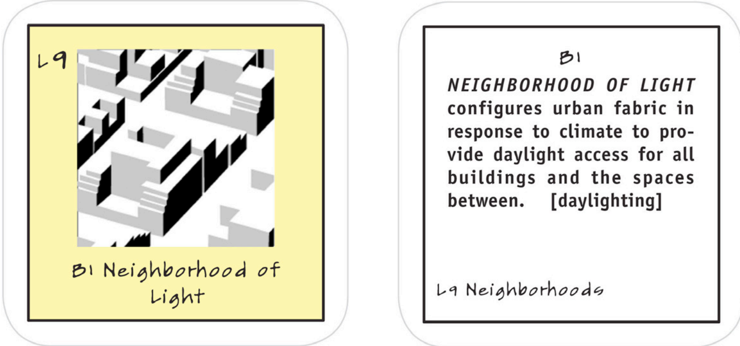
b) 

Figure 4: *(a) Cards for scale/level of complexity (b) Bundle tile example*

from a built example, along with its name, strategy number, and level of complexity designation (L1, L2, etc.). The back side gives more information: the strategy or bundle number, its defining "strategy statement," the energy issues it addresses (heating, cooling, daylighting, etc.), and its level name.

5 OUTLINE OF INSTRUCTIONS FOR PLAYING *BUNDLE-UP!*

The game can be played by one person (as solitaire) or several people in collaboration. It can also be played by having different teams create variations on the same bundle. This is a good way to arrive at *core* strategies (ones that have workability in all of a bundle's variations). Instructions for play:

1) Place your colored Bundle Tile (or create one) in the dashed bundle square on the top.

2) Each strategy has a scale and can only be used at that scale.

3) Choose critical strategies (or your best guess for candidates) from the deck of Strategy Tiles and place them inside dashed bundle "wrapper." These will become either core or situational strategies. You may start with any strategy that you think would be very important to the design scheme.

4) Place less critical refiner strategies at their designated scale, but outside the bundle wrapper.

5) Examine your set of strategies for their interactions and add, subtract or substitute strategies to create greater synergy between strategies to solve the bundle's energy issue(s). Debate the importance of different strategies, moving them inside or outside the bundle wrapper.

6) Now identify the strategies that are the three most critical—at least one at each scale—that are critical to "almost every building" in your situation. Place these in the bold core squares. If desired, you may add up to 2 more core strategies.

7) To test your choice of core strategies, think about whether or not each would still be effective in the other situation(s) of the bundle problem. If playing in teams, debate with the other team. If playing in one group, it is useful to assign different players to advocate for the needs of a particular bundle variation.

8) There is no one right solution, but some are better than others, and solutions that follow the rules are all acceptable. When satisfied with your solution, or your group has reached consensus, record it on the Bundle Capture Form (a reduced version of the game board).

9) HAVE FUN!!! Design. Repeat.

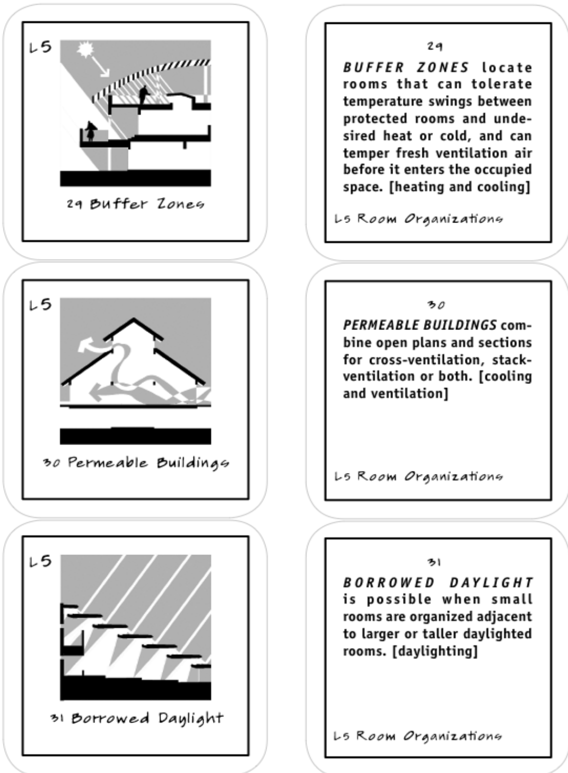


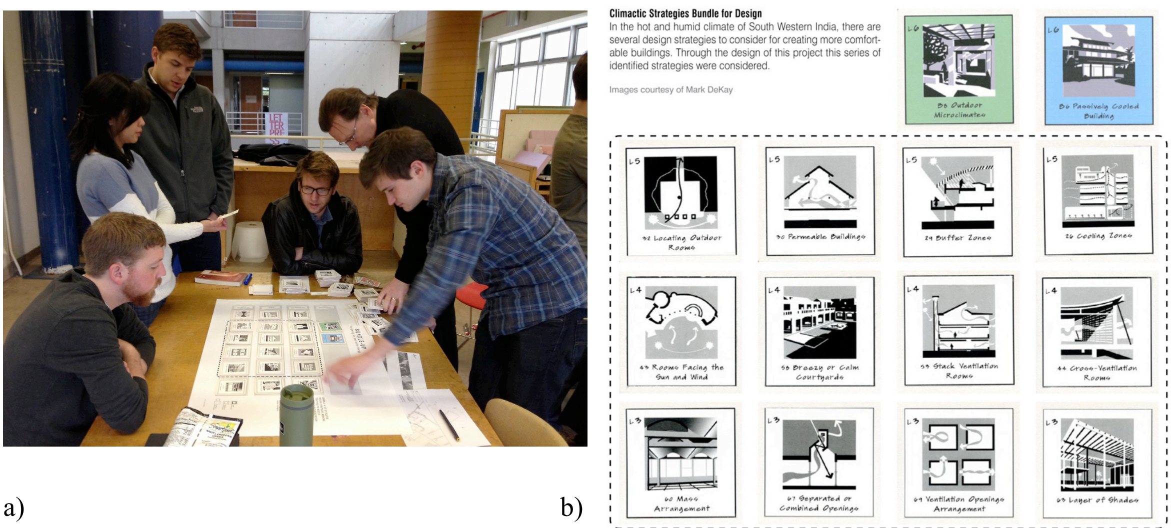
Figure 5: *Strategy tile examples*

6 PROTOTYPES AND TESTING

A rough, limited scope prototype with one bundle and only cooling strategies was created, and an initial test was run with peer teachers at the 2012 annual curriculum meeting of the Society of Building Science Educators. Two teams of architects and design professors debated over and created bundles for hot-humid and hot-arid variations of a PASSIVELY-COOLED BUILDING bundle. Feedback was very positive. The members offered suggestions for improvement, mainly to the instructions and options given to users. Overall, they agreed that the game was a good learning tool and that they had actually learned something themselves in the process of playing. The teachers enjoyed learning in a group together and saw possibilities for transforming the typical architectural technology class that primarily uses individual learning approaches and also noted the potential as a design tool in design studio classes.

Figure 6: *Testing Bundle-Up! with the Society of Building Science Educators*

The next prototype, with a complete set of bundles and strategies, along with revised instructions, was then tested in two classroom settings: fifth-year undergraduate design studios in Spring and Fall terms of 2013 and a second-year "Introduction to Architectural Technology" course in Spring of 2013 and 2014. The lower level instruction in a class of 65 students made use of an instructional video created by the author with two advanced students. In one semester, upper level students designed housing for a village in Gujarat India, collaborating with Professor Sharad Sheth's fourth-year students from Sardar Vallabhbhai Patel Institute of Technology, Vasad. University of Tennessee students are shown playing *Bundle-Up!* in Figure 7a. A team working on housing design for the village of Waghnagar developed a composite bundle for a PASSIVELY-COOLED BUILDING and an OUTDOOR MICROCLIMATE, shown in simplified form in Figure 7b. Their scheme for two variations on low-energy climate-responsive courtyard houses built with local materials and labor skills is shown in Figure 8.



a) b)

***Figure 7**:* *(a) Bundle-Up! in design studio (b) Hybrid custom bundle for Gujarat housing design*

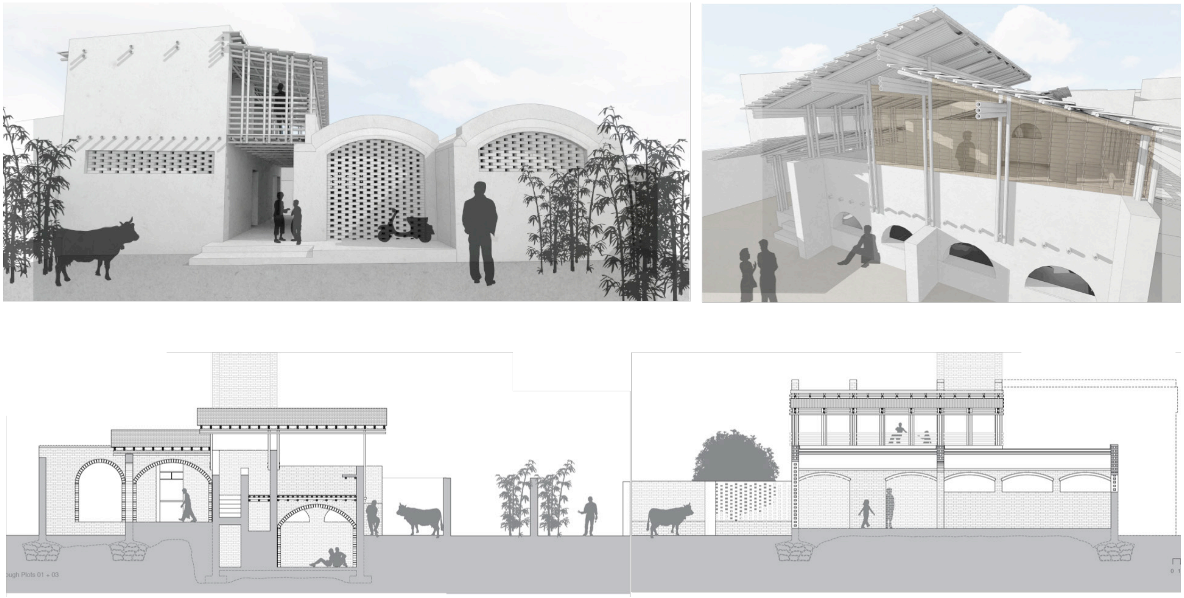


Figure 8: 5th-yr studio project, housing in Waghnagar, Gujarat, designed using SWL bundles

Figure 9: 5th-yr studio project, brewpub in Marfa, Texas, designed using SWL bundles

In another semester, fifth-year students used *Bundle-Up!* to help design a net-zero energy brewpub and beer garden in seven different U.S. cities, each set in a different climate. One team's design for warm-dry Marfa, Texas is shown in Figure 9. It includes passive cooling, heating, and daylighting strategies from *Sun, Wind & Light*, 3rd edition [1]. They also used the new *SWL Tools* spreadsheets to calculate energy demand and size photovoltaics to become a plus-energy project.

The lower-level students used *Bundle-Up!* as a part of a sequence of passive design exercises that design a net-zero energy bioclimatic residence, again in multiple climates. In all of these cases, students developed their designs in collaborative teams of two to four students. Figure 10 shows an example a PASSIVELY-COOLED BUILDING bundle developed in the exercise, a student team using *Bundle-Up*! in the design process, and a second-year scheme for a net-zero energy residence in the mixed-humid St. Louis climate. As a result of these and other classroom innovations, the instructor/author was awarded the Chancellor's Award for Teaching Excellence 2014 at the University of Tennessee.

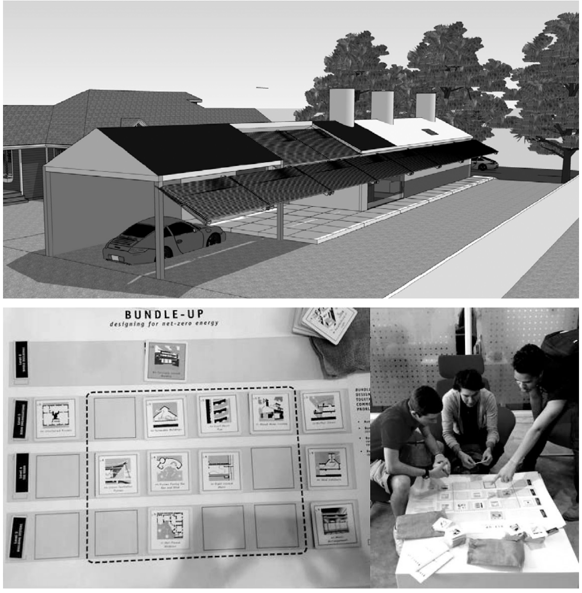


Figure 10: *Student net-zero residence designed using Bundle-Up! in technology class; example exercise bundle; game in student design process*

CONCLUSIONS AND FUTURE PLANS

The next step in testing and revision will be a workshop for practicing architects in October 2014. In theoretical terms, observing users playing *Bundle-Up!* many times and applying their results in designing buildings have suggested the need to expand the *Sun, Wind & Light* knowledge structure. Bundles, as defined in *SWL,* cross a limited range of three scales in the nine-scale system of *SWL* that ranges from materials to neighborhoods. The development question is, “Can the bundle concept and the *Bundle-Up!* game be expanded to include mapping the full range of design strategies employed in a specific design?”

While the game is clear and useful as a learning or design activity, it is important to place it for students within a clear design process context. Students need assistance in knowing when to employ the bundle concepts and more specific guidance about what to do with the game results. To this end, future class exercises will guide a more explicit design process that involves multiple uses of the game in a sequence of different problem variations. Examples might include generating building design bundles for passive heating, cooling, and lighting, or using *Bundle-Up!* to explore a responsive envelope that addresses multiple energy issues.

Perhaps the most common request is for an iPad app or other electronic version of the game tied to its *SWL* knowledge base. The author is currently seeking technical collaborators and funding.

Through application and feedback in different settings and class types over a two-year period, several conclusions may be drawn. Students have found the *Bundle-Up!* game useful as a step in the process of designing passive and net-zero buildings. It requires them to choose carefully and to narrow their design options strategically. Via the game, the relatively complex *SWL* knowledge structure becomes more accessible to both beginning and advanced students. Playing *Bundle-Up!* seems intuitive and fun. Making more fun of understanding climatic design was the game’s real purpose. One peer teacher found, “It teaches systems thinking across multiple scales with none of the systems thinking jargon.” Another reported, “This really supports integrative ecological thinking in a very concrete architectural way.” Students’ responses from feedback surveys are consistent in their appreciation of learning in collaborative dialogue and the teamwork required by *Bundle-Up!,* in contrast to many of their other classes. They enjoy learning in a hands-on, project-based setting, working together with their peers, rather than working in competition with them.

Digital files for printing and making *Bundle-Up!* are available from the author.

ACKNOWLEDGMENTS

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Session 6B : Low energy materials and technology

PLEA2014: Day 2, Wednesday, December 17
14:10 - 15:50, Compassion - Knowledge Consortium of Gujarat

Integrated dehumidification and downdraught evaporative cooling system for a hot-humid climate

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ABSTRACT

Unlike in hot-dry climates, in hot-humid climates evaporative cooling techniques are not readily suitable for space cooling. In order to effectively use evaporative cooling in hot-humid climates, dehumidification of ambient air is necessary before it passes over an evaporative medium for cooling. The present study explores the combined process of dehumidification and evaporation and its effect on thermal comfort in a typical small residential building located in a hot humid climate. A novel system has been investigated with the combination of an Earth Tube Ventilation (ETV) (for pre-cooling of air), a rotary wheel desiccant dehumidifier (for dehumidification) along with a Passive Downdraught Evaporative Cooling (PDEC) tower (for evaporation) in that order.Parametric simulations using the EnergyPlus tool have been conducted in order to determine the critical dimensions and parameters of the proposed system, such as desiccant system sizing, PDEC tower height, and air and water flow rate at various points of the system. Results of indoor air temperature, humidity levels and volumetric air flow rates in the building spaces were obtained to study the influence of the proposed combined system on human thermal comfort. On a typical hot day the results from the proposed system show a relatively constant indoor air temperature of 28 °C (as opposed to peak indoor temperature of 36 °C occurred by means of natural ventilation) and indoor relative humidity in the range of 62 % - 68 %. The volumetric airflow rate from the outlet of the PDEC tower is in the range of 2.97 - 3.41 m^3/s which is well within recommended levels for a dwelling unit. The proposed system displays a significant potential for providing space cooling in hot-humid climates as it paves an alternate way to the conventional energy consuming vapour compression Air Conditioning units.

INTRODUCTION

Space cooling techniques become inevitable in extreme hot-dry and hot-humid climates where building form and construction alone cannot ensure indoor thermal comfort. Evaporation of water has been one of the available techniques used for space cooling. Special architectural features such as wind towers were used in hot-dry climates to direct the prevailing winds over a wet body like *khuskhus* pads, water filled clay pots etc. to enhance evaporation. However, high humidity in the ambient air inhibits the use of direct evaporative cooling in hot-humid climates and dehumidification of the air is necessary before it passes over an evaporative medium for cooling. This study explores an alternate to conventional vapour compression based domestic air conditioning units by using dehumidification and evaporation in a typical residential building in a hot- humid climate in India. A combination of a cooling system

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consisting of a rotary wheel desiccant dehumidifier along with a Passive Downdraught Evaporative Cooling (PDEC) tower has been devised. An Earth Air Tunnel (EAT) for precooling of intake air has later been added to the original cooling system after analysing the preliminary results. Simulations were run with EnergyPlus to conduct a parametric analysis of the proposed system and to study its influence on thermal comfort.

PASSIVE DOWNDRAUGHT EVAPORATIVE COOLING SYSTEMS

Evaporative cooling is based on the conversion of sensible heat to latent heat. When water evaporates, it uses up the heat from the surrounding air to change phase from liquid to vapour and this result in lowering the temperature of the surrounding air. A typical configuration of a passive downdraught cooling system has a tower to draw in air into the space. The air is passed over an evaporative medium placed below the tower inlet, gets cooled and enters the space through an outlet at the bottom of the tower. A passive downdraught was thus created through the evaporation of water within this air-stream and the necessary air circulation was achieved through either by buoyancy or by wind assisted natural ventilation.

However, modern PDEC towers include energy intensive components like fans and pumps to enhance downdraught or to increase flow rates and are referred to as Passive and Hybrid Downdraught Cooling (PHDC) (Ford, Phan, & Francis, 2009). To increase the evaporation of water, large droplets of water are sprayed into the air stream (e.g. by a shower tower) or a mist of water is added to the air stream (e.g. by misting nozzles in a misting tower) instead of letting the air passing over wetted pads and clay water pots. In this paper, shower tower configuration of PDEC is selected as it represents a typical system used in practice. A shower tower PDEC (PHDC) proved to be a worthy option in meeting the cooling needs of the Torrent research centre building in Ahmedabad (Leena & George, 1997). The system provided an alternative to the use of conventional Air Conditioning in such hot climates during hot-dry season. However, reliance on conventional air conditioning was recommended for the hot-humid season. This system can also be well integrated to the existing buildings. An example of such an application is in Portugal, where an existing chimney of a building has been modified to be used as a PDEC tower (Melo & Guedes, 2006). Its performance was studied by measuring the thermal parameters and humidity levels and compared against a mathematical model. The results for PDEC were encouraging, but it was concluded that a PHDC was performing better over a PDEC (Melo & Guedes, 2006).

DESICCANT DEHUMIDIFICATION

Desiccant dehumidification is based on the principle of sorption with the use of desiccant chemicals. Sorption occurs due to difference in the vapour pressure exerted by the moisture in the air on the surface of desiccant which offers an area of low vapour pressure (Munters Corporation, 2002). Liquid desiccant dehumidifiers in general are large systems and are used to condition large spaces. Solid desiccant dehumidifiers are available in different sizes, configurations to suit for application in residential buildings. Two popular solid desiccant configurations that suit residential applications are packed bed and rotary desiccant wheel.

Packed bed dehumidifier consists of loosely packed silica gel beads. Ambient air is passed over this desiccant bed and the dry air is circulated into the space. It has found application in residential units in a configuration called desiccant enhanced nocturnal radiation (DESRAD) cooling and dehumidification. Chung et al., 1995, Satio (1993), Techajuntaa et al. (1999) further investigated DESRAD concept in various configurations and concluded it can be used in domestic air-conditioning in tropical humid climates.

Rotary Desiccant Wheel (DW) dehumidifier consists of finely divided desiccant silica gel beads that are impregnated into a semi-ceramic structure, which in appearance resembles corrugated cardboard that has been rolled up into the shape of a wheel. The wheel rotates slowly between two air streams called the process air and reactivation airstreams. The process air flows through the flutes formed by the corrugations, and the desiccant in the structure absorbs the moisture from the air (Figure 1 process A-B). Re-activation (Figure 1 B-C) is the hot air (blown by a hot air blower) necessary to regenerate the saturated desiccant. Following reactivation, the hot desiccant rotates back into the process air (Figure 1 C-A), where a small portion of the process air cools the desiccant so it can collect more moisture from the balance of the process airstream. (Munters Corporation, 2002). Commercial desiccant products in the HVAC industry are mostly available in rotary desiccant wheel (DW) configuration.

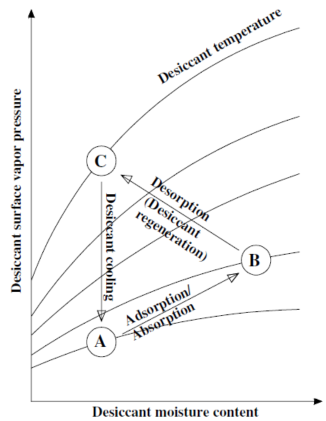


Figure 1 Desiccant dehumidification and regeneration processes (Mazzei et al. 2005)

While a rotary DW dehumidier consumes more energy than a packed bed it has been chosen for the present study because the DW system can be easily and precisely sized with available modelling tools to fit a building case. Modelling a packed bed on the other hand involves dependence either on experimental data or rigorous analytical calculations with assumptions to be made which was beyond the time scope of the study.

METHODOLOGY

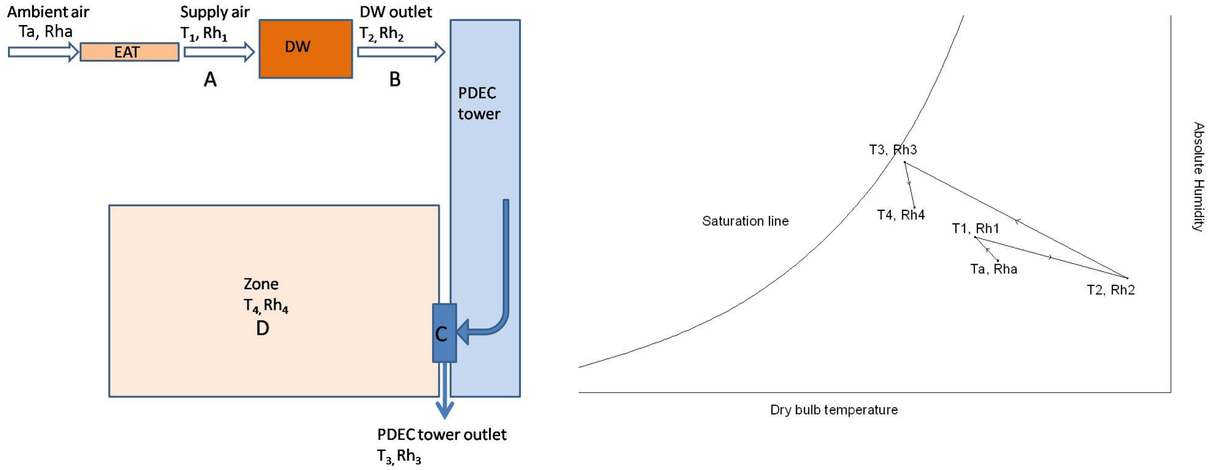
Location and Climate analysis

The location selected for the current study is Visakhapatnam city (Lat 17.72, Lon 83.23) in the state of Andhra Pradesh in India and where the climate is categorised as tropical hot-humid climate. In peak summer the temperature reaches as high as 38 °C and in winter it reaches a minimum of 15 °C. The diurnal variation of temperature during hot summers is usually 5-6 °C. The outdoor relative humidity levels are in general above 60% for most of the year. Relative humidity is low at noon and reaches peak during early morning before the sunrise and again drops as the day progresses .

Description of the proposed system and sequence of operation

The proposed system consists of a rotary Desiccant Wheel dehumidifier (DW) which is integrated with a Downdraught Evaporative Cooling shower tower (PDEC tower) through which the air is supplied into the space (Figure 2 a). An Earth Air Tunnel has later been added to the DW+PDEC system after observing the preliminary results in order to pre cool the supply air drawn into the Desiccant Wheel.

The ambient air at temperature T_a and relative humidity Rh_a is drawn into the EAT and leaves the EAT at a temperature T_1 and relative humidity Rh_1. The air at T_1 and Rh_1 is then drawn into the inlet of DW from the outlet of the EAT. The air at the outlet of the DW is called the process air and it has been dehumidified and conditioned to a temperature T_2 and relative humidity Rh_2. The process air at T_2 and Rh_2 is then supplied to the top of the PDEC. T_3 and Rh_3 are the air temperature and relative humidity at the outlet of the PDEC tower which is directly supplied for cooling the indoor space. T_4, Rh_4 is the final temperature and relative humidity in the zone and it is expected to be less than the ambient T_1 and Rh_1 for the system to be able to perform well. The psychrometric representation of the proposed system can be seen in Figure 2 b.



a) b)

Figure 2 a) Graphical representation of the proposed system b) System representation on a Psychrometric chart

Description of a typical dwelling unit to which the proposed system is attached

A typical dwelling unit has been modelled as three thermal zones (Figure 3). Zone 2 is connected to the proposed system of integrated dehumidifier and PDEC tower and it is referred to as zone henceforth. All rooms have a wall to window ratio of 33% which is typical in the region. The floor to ceiling height is 2.8m. The worst possible scenario is assumed for shading during the cooling period, i.e. there are no shading devices or overshadowing from the surroundings. Typical building materials used in the region are assumed for the constructions and their U-Values (in W/m^2K) are: exterior walls - 1.946, interior walls - 1.735, roof slab - 4.6, floor slab - 0.894 and windows 5.71 (with an SHGC of 0.567).

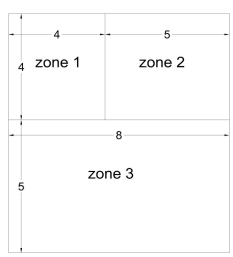


Figure 3 Typical dwelling unit (all dimensions in meters)

MODELLING THE PROPOSED SYSTEM

The EnergyPlus whole building dynamic simulation program was used to simulate the EAT, DW and PDEC components. However, the whole proposed system of this study (i.e. ambient air→ EAT→ DW → PDEC → Building zone) could not be modelled in one simulation because of the limitations of the tool to assemble such a configuration in a single sequence. For this purpose, a total of four simulations were carried out in a way that is explained below and summarised in Figure 2:

1. Ambient air→ EAT (A in Figure 2): Precooling of air was simulated using an Earth Air Tunnel. The results of the simulation provide the supply air temperature at T_1, Rh_1 from the outlet of the EAT. The EAT has been modeled with a fan to provide an EAT outlet flow that matches with the supply flow rate demand of the DW dehumidifier.

2. EAT→DW (A to B in Figure 2): The DW was simulated in EnergyPlus using a modified weather file with temperature and relative humidity values obtained from the previous simulation i.e., T_1 and Rh_1 as inputs. The results of this simulation provide the process air at T_2, Rh_2 from the outlet of the DW.

3. DW→PDEC (B to C in Figure 2): The PDEC tower was modelled in the third simulation. Technically, in the EnergyPlus program the PDEC tower simulation takes the inlet temperature and humidity data at the top of the tower from the original weather file. Therefore, the values of actual ambient air temperature and relative humidity in the original weather file were replaced by the output obtained from the 2nd simulation, i.e., with T_2, Rh_2. When this 2nd simulation was run PDEC tower takes T_2, Rh_2 as the inlet values at the top of the tower and the tower outlet temperature and humidity T_3, Rh_3 are obtained. The conditions in zone 2 (T_4 and Rh_4) can in theory be calculated from the same simulation, however in this case the zone conditions cannot be obtained because the temperature and relative humidity values (T_2 and Rh_2) in the weather file for the 3rd simulation were modified from the actual ambient temperature and relative humidity (from T_a and Rh_a) to the DW outlet temperature T_2 and relative humidity Rh_2 in order to be used as inlet conditions of the PDEC tower. This means that the weather file during the 3rd simulation did not include the actual weather conditions and could not therefore be used to define the boundary conditions of the building.

4. PDEC→Room (C to D in Figure 2):The fourth simulation was run to obtain the zone temperatures and relative humidity levels (T_4 and Rh_4). In this simulation boundary conditions were properly set based on the original weather file with ambient air conditions at T_a and Rh_a. The air supplied into the zone from the PDEC tower outlet (i.e. T_3 and Rh_3) has been mimmicked by using a customised EnergyPlus component that supplies air into the zone at desired parameters. The results of this simulation provide the zone air conditions at T_4, Rh_4.

Parametric studies have been done at each component level to optimise the critical parameters that impact in achieving the lowest temperature and relative humidity of the air at each of the outlets. The focus was on optimising pipe length and depth for EAT, velocity of the wheel for the Desiccant Wheel, and water flow rate and height of the tower for PDEC tower. Table 1 gives a summary of the sequence of optimization of various components, which was done based on the above listed parameters. The physical parameters of the proposed system were optimized based on the conclusions drawn from the parametric results. The highlighted area shows the selected case from each stage, which was then carried forward to the subsequent simulation stage.

Table 1 Optimization process

Earth Air Tube	Case 1	Case 2	Case 3	Case 4	Case 5
Pipe length	30	30	30	50	70
Depth	3	5	7	3	3
DW	Case 1	Case 2	Case 3	Case 4	
Velocity (m/s)	2.5	3	3.5	4	
PDEC	Case 1	Case 2	Case 3	Case 4	
Max water flow rate (m^3/s)	0.00001	0.0005	0.005	0.016	
PDEC - height (m)	5.0	5.0	5.0	5.0	
PDEC	Case 5	Case 6	Case 7	Case 8	Case 9
Max water flow rate (m^3/s)	0.0005	0.0005	0.0005	0.0005	0.0005
PDEC - height (m)	3.00	5.00	7.00	9.00	11.00

RESULTS

A period of two representative weeks during which peak outdoor temperatures occur is taken for study (Figures 4 and 6). It can be observed from Figure 4 that there is a significant decrease in the zone temperature in the range of 3-8 °C after adding the proposd system (without EAT) in comparison to the zone temperature without any system and open to natural ventilation. The addition of the EAT further decreases the zone temperature and brings it close to the comfort limits (in the range of 28 – 30 °C).

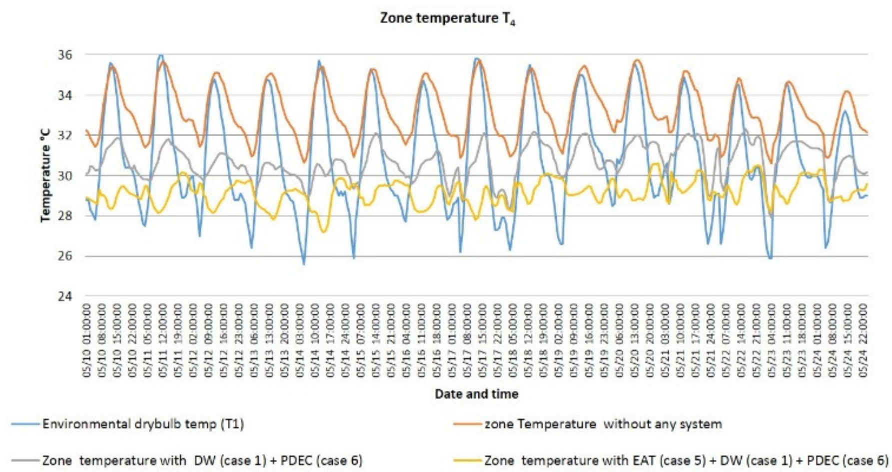


Figure 4 Zone temperature (T_4) after adding EAT (case 5) to pre cool the supply air

A typical warm day chosen from the above two-week period to analyse the diurnal variation in zone temperature and zone relative humidity levels. From Figure 5 it can be seen that zone temperatures during the day are lower than that of the night for the system configuration with EAT (case 5) + DW (case 3) + PDEC (case 6). The zone air temperature increases in the night and at times exceeds the ambient air temperature (see Figure 5).

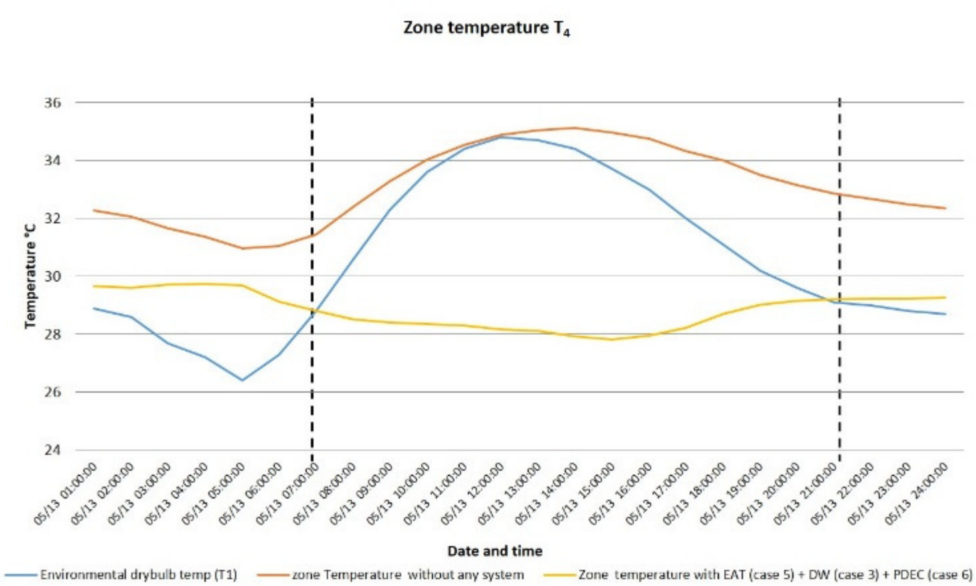


Figure 5 Diurnal variations in zone temperature (T4)

The relative humidity in the zone with the proposed system was lower during daytime and higher during the nights than the relative humidity values of the naturally ventilated case. However, zone relative humidity levels are maintained well below the maximum permissible level of 75% (Figure 6) (CIBSE, 2006) throughout the period of the study.

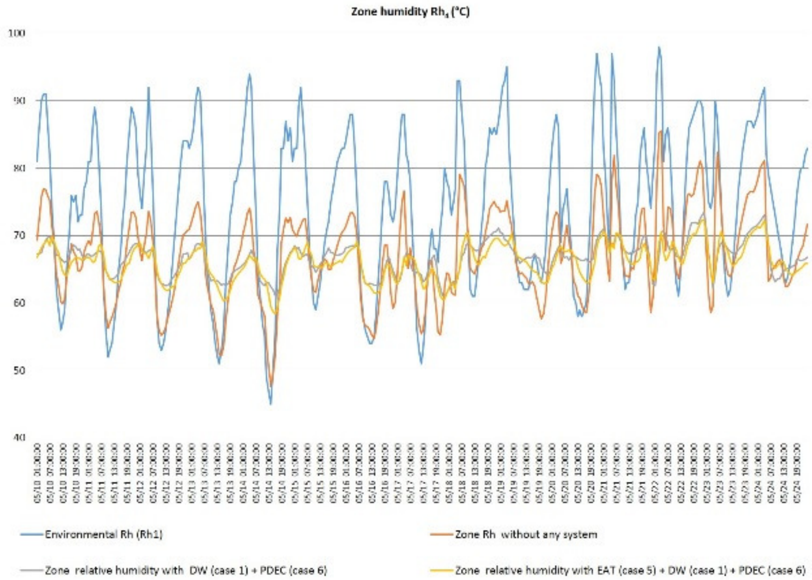


Figure 6 Zone humidity (Rh4) after adding EAT to pre cool supply air

Figure 7 shows that the proposed system results in a slightly higher relative humidity (up to 8%) compared to the naturally ventilated zone humidity levels during the day. However, during the nights the system reduces (by up to 7%) the relative humidity in the zone. An air flow rate of 2.97 - 3.41 m^3/s was also observed at the outlet of the PDEC tower ensuring the recommended ventilation levels within the space as per ASHRAE (2009) for redidential dwellings.

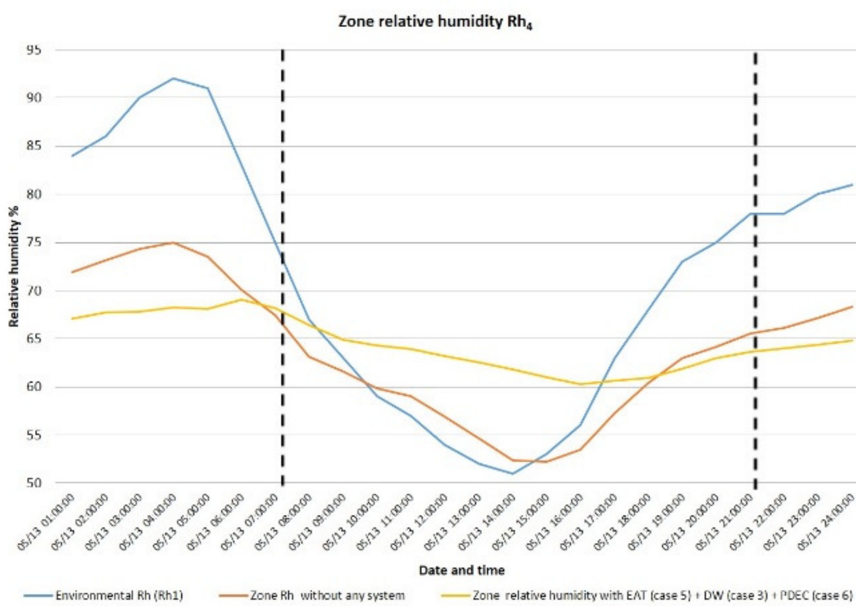


Figure 7 Diurnal variation in zone relative humidity (Rh4)

CONCLUSION

An integrated cooling system of desiccant dehumidifier and PDEC was evaluated for a typical dwelling in a hot humid climate in India after being combined with an earthtube ventilation system. A process for enabling the simulation of the proposed system has been reported. The system's performance was investigated with a parametric analysis and it was found that by using the EAT+DW+PDEC system as opposed to using natural ventilation the peak indoor summer temperatures were reduced by about 8 °C while indoor relative humidity remained below 75%. The proposed system could provide space cooling in hot-humid climates and could be an alternative to high energy consuming conventional vapour compression AC units.This study analysed a worst-case scenario of a building without any shading and by assuming typical materials that are not of high thermal standards. With improvements however in building designs, the proposed system could ensure good levels of indoor thermal comfort.

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Thermal Performance of a Passive Cooling Louver System to Form Cool Microclimate in Urban Residential Outdoor Spaces

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ABSTRACT

A passive cooling louver system (PC louver), which is an aluminum louver partition coated with hydrophilic and water absorbing film, was developed in order to form a cool microclimate in urban residential outdoor spaces in hot and humid regions. The combination of hydrophilicity and water absorption of the film enhances water diffusion of the surface of PC louver. Hence, when a PC louver is watered from the top, the entire surface becomes wet, which enhances its evaporative cooling effect. The PC louver was designed to shade direct solar radiation, provide radiation cooling and ventiration cooling with cooled airflow. In this research, the thermal performance of the developed PC louver in outdoor environment was evaluated. As a result, the PC louver's surface was fully wetted and its surface temperature was approximately the ambient wet bulb temperature throughout the day. Temperature of the air passing through the PC louver decreased 2–3 °C, which achieved the expected cooling performance as a passive cooling system.

INTRODUCTION

In urban cities in hot and humid regions, the outdoor thermal environment has become a serious issue as the danger of heat stroke has increased. In these regions with a large amount of rainfall during the summer, the application of a passive cooling design using solar shading and evaporative cooling is focused (Hoyano et al., 1995). In residential area, it is expected to form cool microclimate in semi-outdoor spaces, so as to improve thermal comfort for both indoor and outdoor spaces.

Therefore, we developed a "Passive Cooling Louver System (PC louver)" as a residential exterior item (Figure 1). Louvers in general are able to shade solar radiation while penetrating air flow. In addition, by wetting the louver's surface, the surface temperature of the louver is expected to decrease by the latent heat of the evaporating water. Thus by adding the function that enables to wet the louver's entire surface, the following passive cooling effects can be expected : 1) solar shading, 2) radiation cooling, 3) ventilation cooling with cool airflow.

In this paper we first summarize required performances of PC louver and approaches to satisy these requirements. Subsequently, we verified the thermal performance of the PC louver through experiments in an outdoor environment. Besides, since it is necessary to predict the cooling effects at the architectural design stage, the thermal performance of the PC louver is evaluated in means of revealing the heat balance of the PC louver, in order to build a heat transfer model. However, this paper describes the achievements of thremal performances of the PC louver compared to the required performances, and the construction of modeling is performed in the next step.

DEVELOPMENT OF A PASSIVE COOLING LOUVER SYSTEM

Cooling Potential and Required Performance of the PC louver

Among hot and humid regions, there are cities that the relative humidity during the daytime decreases significantly. For example Tokyo, Japan is a seasonally hot and humid climate, but while the air temperature is above 30 °C during the day, relative humidity tends to decrease to 40–50 %, and wet bulb temperature at about 20–25 °C, which indicates enough potential as a cooling source (AIJ, 2005).

In the previous research (Hoyano et al., 1995), they developed a moist and void brick wall as a passive cooling wall (PCW), and verified that the wet bricks' inner surface temperature lowered to almost the ambient wet bulb temperature in an outdoor environment. Moreover, in the previous measurement and simulation of a semi-enclosed space using PCWs, the mean radiant temperature near PCWs were 2–4 °C less than the ambient air temperature and the air temperature passing through the PCW was lowered to 3 °C at the maximum. (Shirai et al., 1997; He et al., 2009).

The high performance of a PCW is well known through the previous research, but since a PCW is a wall of bricks, its form and utilization is more suitable in public spaces rather than in residences. Besides, moist bricks are effective to provide cooling effect continuously, but being moisted constantly is not a good condition for durability. Therefore, as shown in Table 1, we summarized the requirements for the development of the PC louver to satisfy performances as a passive cooling system together satisfying requirements as an exterior item in residences.

Surface Specifications of the PC louver

For the basic material of the PC louver, aluminium was chosen for its strength and durability. For the surface layer, it is important to wet the entire surface of the louver in order to minimize the surface temperature distribution. Thus, a hydrophilic resin with porous particles (Figure 2(a)) and photocatalyst

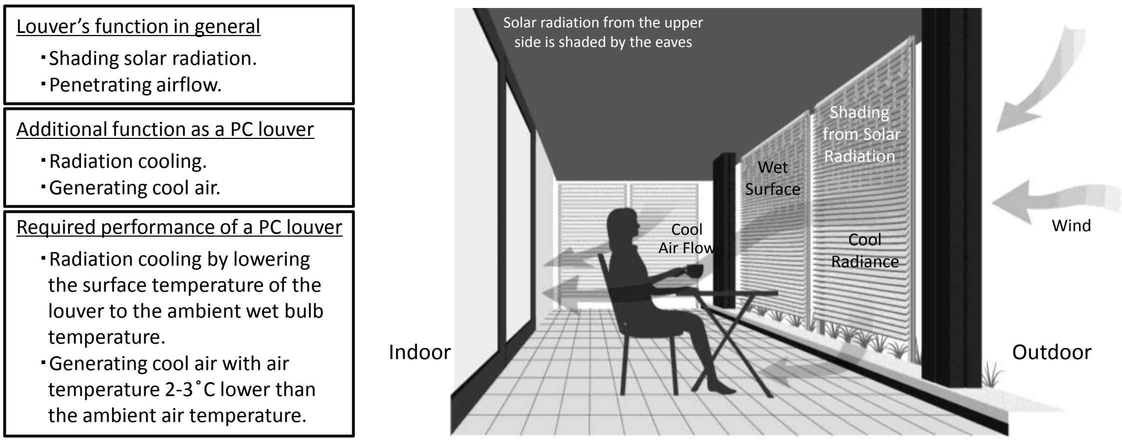
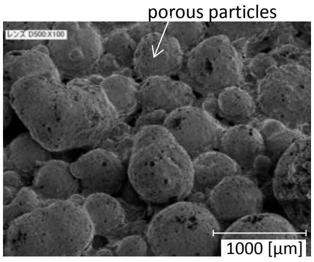


Figure 1 Image of passive cooling effects using a PC louver in semi-outdoor space of a residance.

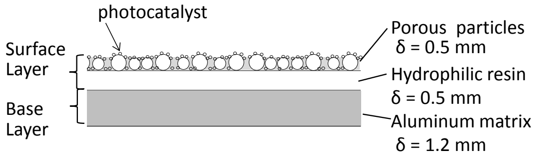
Table 1. Required performances and methods for the development of a PC louver.

Required performances	Methods
1) Shade direct solar radiation to the subject space.	Adjust pitch of the louver's slats.
2) Wet the entire surface of the louver and create uniform surface temperature distribution.	Enhance the hydrophilicity of the louver's surface.
3) Prevent algae, mold or smudge by letting the louver's surface dry easily when it is not in use.	Separate surface layer and base layer, and wet only the surface layer.
4) Enhance heat transfer between cooled louver's surface and air passing through the louver.	Enhance the surface ratio of the louver's slat to the louver's vertical plane.
5) Lower surface temperature of the louver immediately after watering.	Lower heat capacity of the louver by using the hollow aluminium slats.
6) Enable to maximize the shape factor to the subject space.	Manufacture the louver with compact depth and flexible width and height.

Principal component	SiO_2 66.7 %
Particle size distribution	300 – 1000 μm
Volumetric specific gravity	0.4
Water absorption rate	55.8%

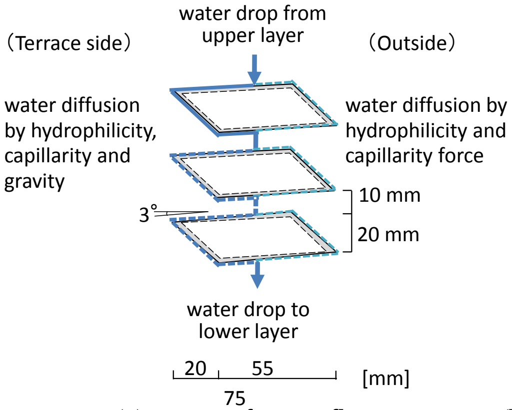


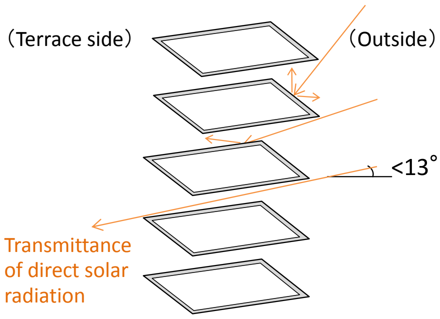
SEM image of porous particles



(a) Characteristics of porous particles. (b) Cross section of the slat's surface.

Figure 2 The characteristics of the slat's surface of the PC louver.





(a) Image of water flow. (b) Image of the transmittance of direct solar radiation.

Figure 3 Description of the PC louver's cross section.

(TiO_2) was coated to the aluminum base (Figure 2(b)). Hydrophilicity of the resin and the porous particles were enhanced by the photocatalyst, and the capillary force of the porous particles aided the diffusibility of the surface water.

Form and Sectional Composition of the PC Louver

The form and the sectional composition of the PC louver were determined mainly with the consideration of water flow and the solar radiation transmittance. The louver's slats are titled 3° down toward the terrace side in order to drain water mainly to the terrace side. In addition, by cutting the edge of slats toward the center, water is led to drop near the center of the next slat (Figure 3(a)).

Space between slats affects the quantity of solar radiation transmittance, evaporation, air permeability, and heat transfer between louver's surface and air passing through the louver. Among these factors, we mainly focused on the effect of solar shading because the amount of solar energy is larger compared to other factors. By narrowing a space between the slats to 10 mm, the louver system allows direct solar radiation to transmit only at solar altitude lower than 13°, which corresponds to approximately an hour before and after the sunset and sunrise (Figure 3(b)).

THERMAL CHARACTERISTICS OF THE PASSIVE COOLING LOUVER SYSTEM

Aim of the Experiment

An outdoor experiment was conducted in order to verify thermal performance of the PC louver in means of clarifying the heat balance of the PC louver's surface. The heat transfer model is expected to be inserted in a microclimate simulation tool (Asawa et al., 2008), which the authours have developed. In order to analyze the spatial distribution of the microclimate in the simulation, the heat transfer model of PC louver is required to be simplified to reduce calculation load. Therefore, a distribution of the surface temperature of the PC louver is verified at the experiment in order to discuss the possibility to treat PC louver's surface as a thermally equivalent semi-permeable vertical plane. A description of the PC louver's heat transfer model is shown in Figure 4.

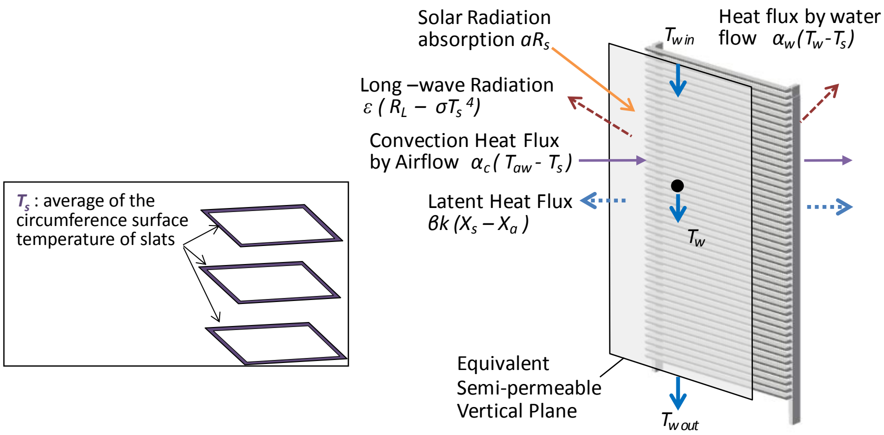


Figure 4 A description of heat balance at the PC louver's surface.
Modeled as an equivalent semi-permeable vertical plane

Measurement Methods

A terrace with the PC louver was constructed in semi-outdoor space of a detached house, facing the southwest direction (220°). The site was open to the predominant wind direction, thus wind flowed into the terrace from the front to diagonal direction of the louver. Two PC louver planes on the front side of the house were attached to the pergola, which the east side louver was wetted during the experiment (the wet PC louver) and the west side louver was kept dried (the dry PC louver) for comparison purposes. The scheme of the PC louver and the measurments are shown in Figure 5 and Table 2.

The measurement was conducted on Oct.1st 2012 and Aug. 4th 2013 to Nov. 29th 2013. Air temperature at at the vicinity of the PC louver was measured using aΦ = 0.1 mm T-type thermocouple set inside a forced draft Φ = 13 mm polyvinyl cylinder (air velocity of approximately 1.5 m/s), in order to reduce the influence of solar radiation. Ambient dry bulb and wet bulb temperature were measured inside a forced draft Φ = 150 mm aluminum cylinder (air velocity of approximately 3 m/s). A water tube with Φ = 6 mm was inserted through the strut to the beam of the pergola. The amount of water supplied was measured right below the water drip tube and the amount of water drainage was measured at bottom of PC louver using a tipping-bucket rain gauge. During the experiment, tap water was supplied at approximately 0.04 kg/min per PC louver's vertical plane. Although, for hot and humid regions with a large amount of rainfall during summer, where the amount of precipitation is enough to cover the evaporation amount, we are working to construct a system to use rain and supply it to the PC louver.

Measurement Results

Wet and Dry PC Louver's Surface Temperature The distribution of the wet state of the louver was difficult to measure, thus surface temperature distribution was measured using an infrared camera. Figure 6 (a) shows the surface temperature distribution of the terrace side and the outside of the PC louver at 13:00 on Aug. 7th 2013, as a representative day of a clear sunny day. Overall, there was about a 3 °C range in surface temperature distribution of the wet PC louver. As shown in Figure 6 (b), the outside surface of the louver had a large distribution of solar radiation due to its ragged form, but the difference in surface temperature was small. This indicates that the quantity of solar radiation does not determin the surface temperature of the wet louver, but the latent heat, as the quantity of evaporation shown in Figure 9, is the main factor. The small distribution in the wet PC louver's surface temperature also indicates that the convective heat flux of water flow is small compared to other heat fluxes at the experimented amount of watter supply. This is also confirmed by the calculation of He et al., (2008) that only a few centimeters of the wet surface's temperature are affected by the water's temperature.

From these result, the small range of surface temperature distribution was confirmed when the entire surface is wet. The range was small enough to use the average temperature as a representative temperature for an equivalent vertical plane, when discussing on the microclimate in residential space.

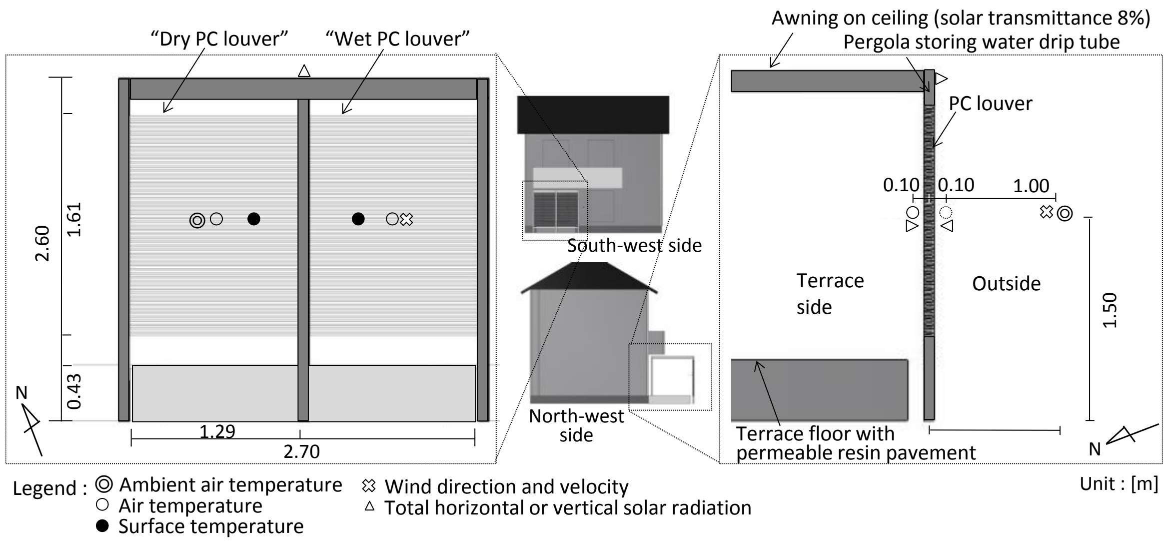
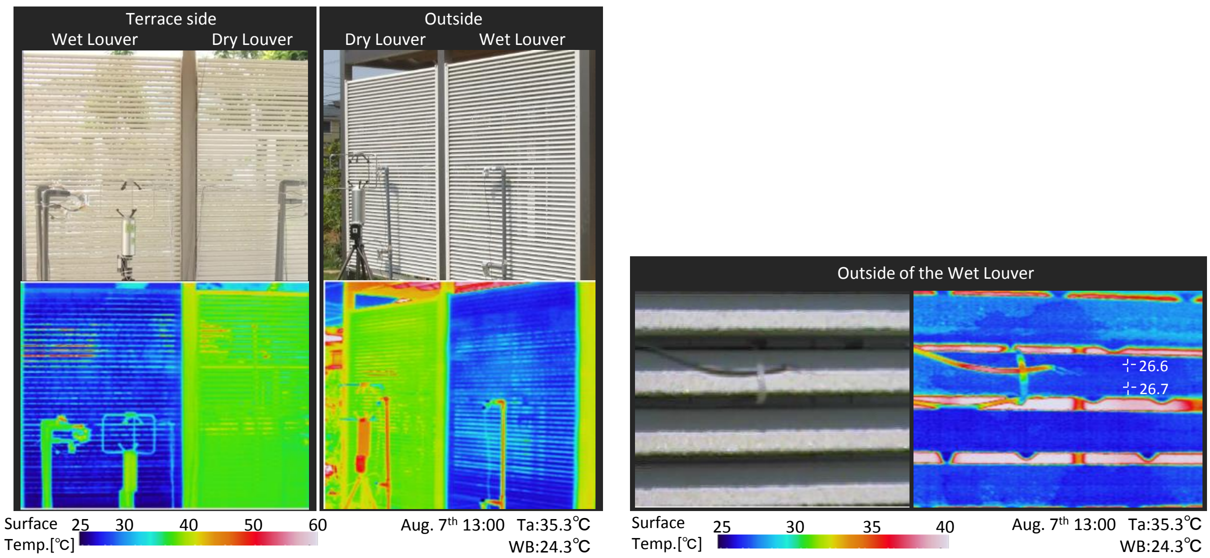


Figure 5 Section of PC louver and measurement points.

Table 2. Descriptions of the Measurement Sensors.

Measurement	Measuring point	Sensor type	Resolution	Interval
Ambient air temperature Ambient relative humidity	GL+9m	Weather Transmitter (WXT520, VAISALA)	±0.3℃ ±3% (<90%RH) ±5% (>90%RH)	1min.
Ambient wind direction Ambient wind velocity	GL+2.3m	Wind vane anemometer	±5° ±0.3m/s	
Dry bulb temperature Wet bulb temperature	GL+1.5m 1m outside from PC louver	Φ0.1mm T-type thermocouple (internal forced draft cylinder)	0.1℃	
Total horizontal solar radiation Total vertical solar radiation	GL+2.6m (top of pergola)	Pyranometer (sensitive waveband:0.3-2.8 μm)	±5%	1sec. / 10sec. / 1min.
Wind direction Wind velocity	GL+1.5m 1m outside from PC louver GL+1.5m 0.15m inside terrace from PC louver	3-D Ultrasonic wind sensor	±2° ±0.1m/s	
Air temperature	GL+1.5m, 0.1m in and outside of PC louver	Φ0.1mm T-type thermocouple (internal forced draft cylinder)	0.1℃	
Surface temperature	GL+1.5m	Φ0.1mm T-type thermocouple	0.1℃	
Surface temperature	GL+1.5m	Infrared camera (sensitive waveband:8-14 μm)	±2℃	arbitrary
Water supply	Below water drip tube	Weight scale	0.001g	
Water drainage	Bottom of PC louver	Tipping-bucket rain gauge (ϕ0.2 m)	±3%	10min.



(a) Terrace side and outside of the PC louver. (b) Enlarged diagram of outside.

Figure 6 Surface temperature distribution of the PC louver.

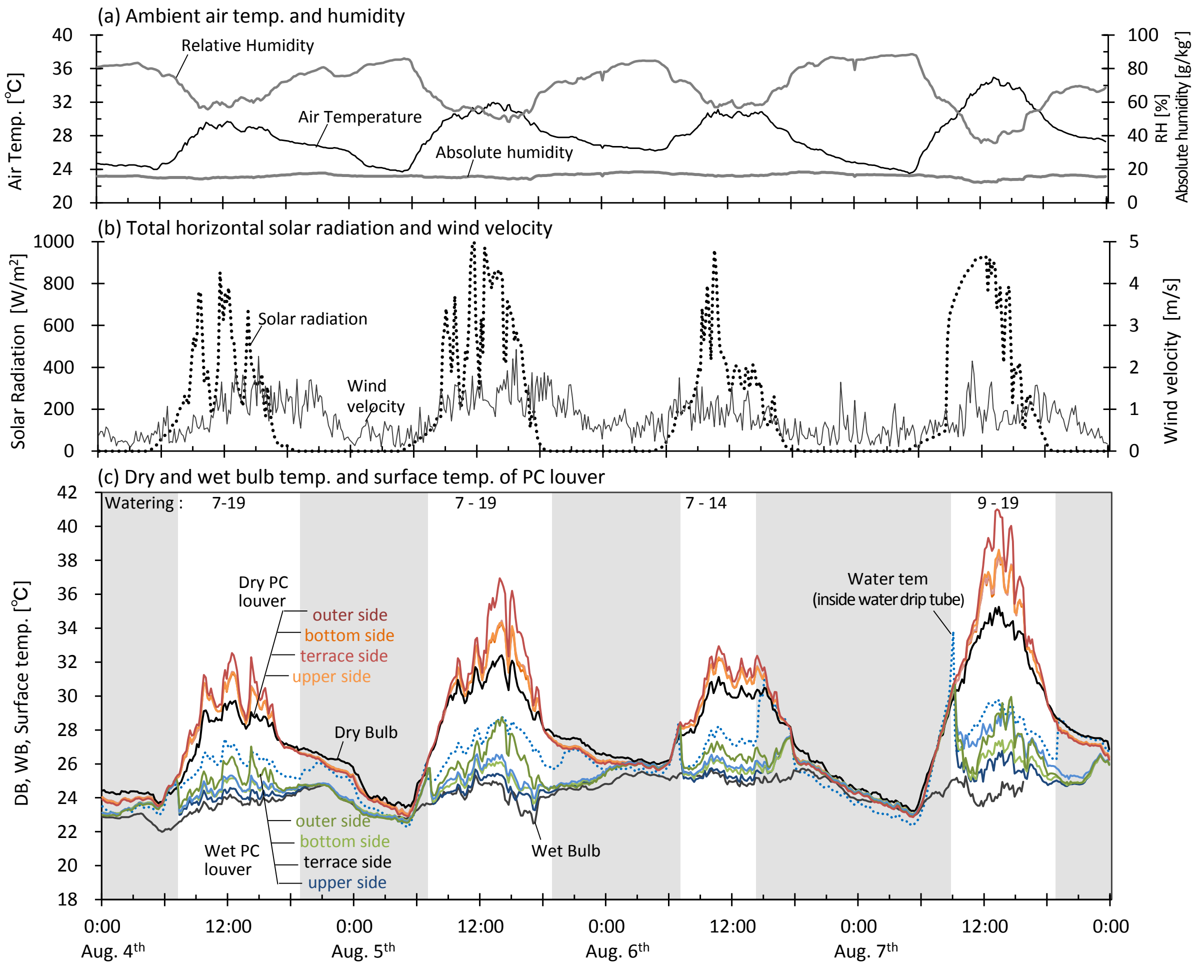


Figure 7 Diurnal surface temperature change of the wet PC louver and the dry PC louver.

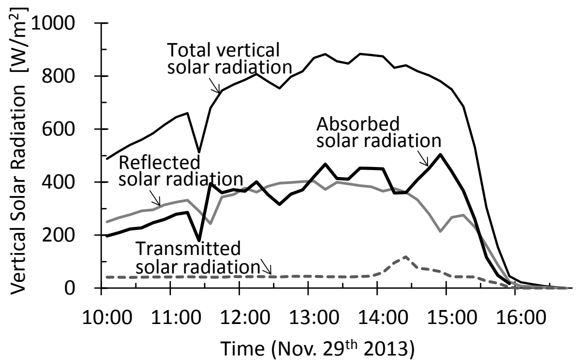


Figure 8 Quantity of Solar reflectance and transmittance.

Diurnal surface temperature change of the PC louver is shown in Figure 7. From Aug. 4th 2013 to Aug. 7th 2013, water was supplied continuously during the daytime as shown in the white bands in Figure 7. Surface temperature of the dry PC louver exceeded 40 °C, while the surface temperature of the upper side and terrace side of the wet PC louver was only 0–1.5 °C higher than the ambient wet bulb temperature, which indicates the effect of evaporative cooling at the louver's surface.

Transmittance and Absorption of Solar Radiation The amount of transmitted solar radiation was approximately 50 W/m^2 during daytime in a sunny day, which is about 5 % of the incident solar radiation (Figure 6). Direct solar radiation was calculated to transmit at an hour before and after the sunset and sunrise, but solar transmittance did not increase, since the quantity of solar radiation was already small at these times. Solar radiation absorption was calculated by the deduction of transmitted solar radiation and reflected solar radiation from incident solar radiation, and the solar radiation absorption was approximately 47% during the daytime.

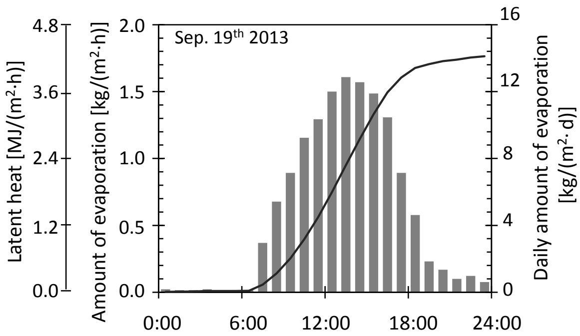


Figure 9 Evaporation rate and daily amount.

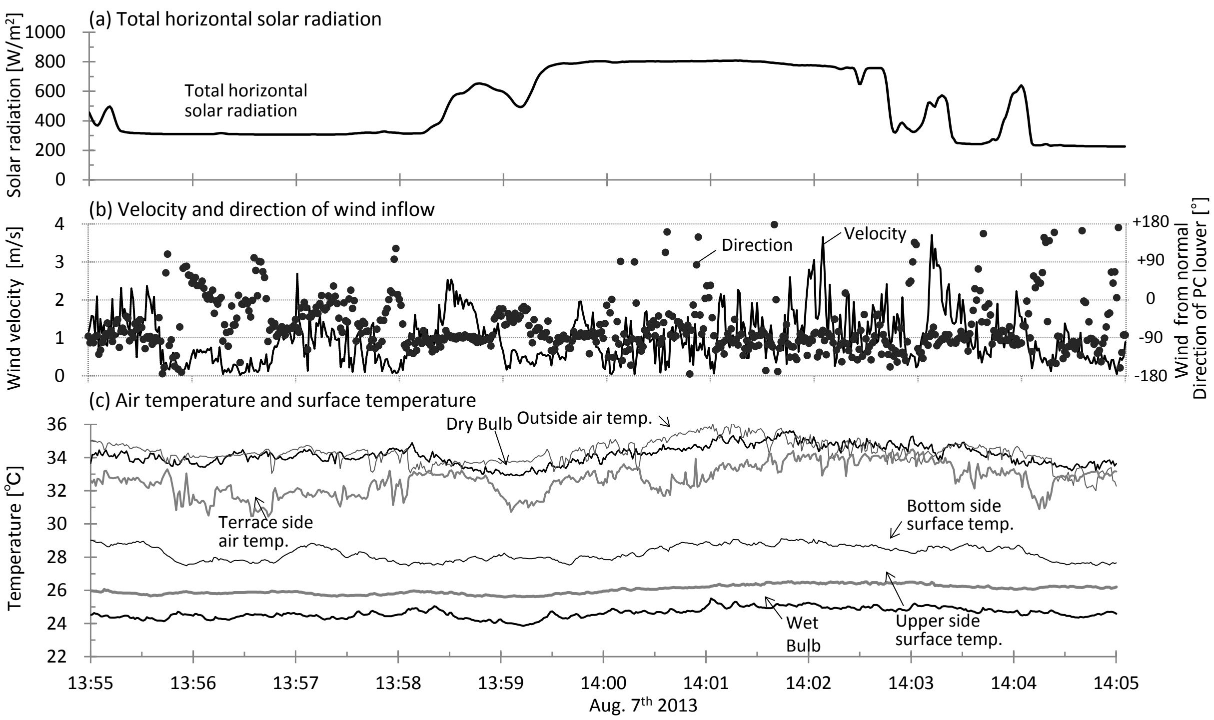


Figure 10 Air temperature at the vicinity of the PC louver. (Data interval: 1sec.)

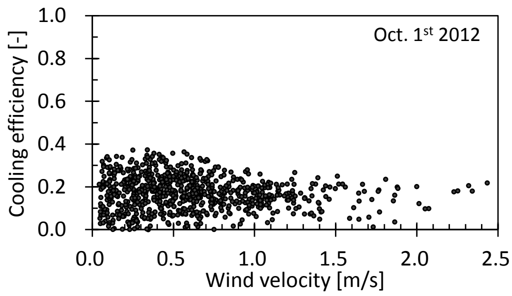


Figure 11 Cooling efficiency of air passing through the PC louver.

Evaporation Rate Evaporation rate per vertical surface plane of a representative sunny day is shown in Figure 9. Water was supplied continuously for 24 hours during this period. From the experimental results, 14 kg/m^2 of water evaporated in a day, which is equivalent to 34 MJ/m^2 of latent heat flux. This is about two to three times larger than that of standard water retentive pavements.

Air temperature in front and behind the PC louver Wind direction in Figure 10 is shown by considering the normal direction from outside to PC louver as 0°. When wind speed was larger than 0.5 m/s, air temperature at the vicinity of the PC louver varied depending on wind's direction. When wind direction is 0° to ±45° at 13:56–13:58, air temperature decreased approximately 2 °C in the terrace side compared to the outside air temperature. When wind direction is ±45° to ±90°at 14:02–14:03, air temperature difference was not significant. Air temperature in terrace side also decreased with a breeze (wind velocity less than 0.5 m/s) at 13:59 and 14:04. Here, the cooling effeciency of wind penetrating the PC louver is evaluated by the following index η, based on the ambient wet bulb temperature:

$$\eta = (T_a - T_l)/(T_a - T_{wb}) \tag{1}$$

Figure 11 shows the calculated data when wind continuously passed through the louver from the normal direction for more than 3 sec. η tended to stabilize at 0.2 when wind velocity is larger than 2 m/s, and distributed between 0–0.4 at breeze. This is a similar feature to the former PCW that the maximum value of η is recognized at breeze, but stabilizes at smaller value as wind velocity increases.

CONCLUSION

This study investigated the potential use of an evaporative cooling system during daytime in urban cities in hot and humid regions. A "Passive Cooling Louver System," coated with hydrophilic resin, porous particles, and a photocatalyst was developed as an exterior material for residences.

From the outdoor experiment the following thermal performances were revealed: 1) The surface temperature of the wet PC louver was approximately the ambient wet bulb temperature. 2) The distribution of the wet PC louver's surface temperature was small enough that it can be modeled as an averaged value of an equivalent vertical plane. 3) Transmittance of direct solar radiance is few. 4) The maximum amount of daily evaporation of the PC louver is approximately 14 kg/m^2 (≈ 34 MJ/m^2 of latent heat) per vertical plane. 5) Air temperature at the vicinity of PC louver decreased by 3 °C at most. From these results, the required cooling performance as a development of the PC louver was confirmed. For the next step, we will construce a thermal transfer model of the PC louver and incorporate it to a microclimate simulation tool, in order to aid spatial design to form cool microclimate.

ACKNOWLEDGMENTS

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NOMENCLATURE

Φ	=	Diameter [mm]	ε	=	Emissivity [-]
R_L	=	Long wave radiation [W/m^2]	σ	=	Stefan-Boltzmann constant [-]
T_s	=	Surface temperature [°C]	T_{aw}	=	Air temperature at windward of PC louver [°C]
T_{wb}	=	Wet bulb temperature [°C]	T_{al}	=	Air temperature at leeward of PC louver[°C]
T_w	=	Water temperature [°C]	η	=	Cooling efficiency [-]
k	=	mass transfer coefficient [-]	β	=	Evaporation efficiency [-]
α_c	=	Convection coefficient between air and the surface of PC louver[W/(m^2 K)]			
α_w	=	Heat transfer coefficient between water and the surface of PC louver[W/(m^2 K)]			

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Embodied energy and CO_2 emissions of building materials for residential buildings in Jakarta and Bandung, Indonesia

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ABSTRACT

The objective of this study is to evaluate the current building material stock and future demolition waste for urban houses using a material-flow analysis in Jakarta and Bandung. Their embodied energy and CO_2 emissions are also analyzed by using an input-output analysis method. The actual on-site building measurements were conducted in Jakarta (2012) and Bandung (2011), focusing on unplanned houses, to obtain building material inventory data. A total of 297 and 247 houses were investigated in Jakarta and Bandung, respectively. These houses were generally classified into the following three categories: simple (45%), medium (39%) and luxurious houses (16%). The results show that overall, the averaged material quantity per m^2 used for the houses is 2.14 ton/m^2 in Jakarta and 2.06 ton/m^2 in Bandung. Two scenarios with zero and maximum reuse/recycling rates were designed to predict future demolition waste and embodied energy/CO_2 emissions of building materials in Jakarta. Closed- and open-loop material flows were applied. The maximum reuse/recycling rates not only decrease material waste (0.93-1.22 ton/m^2) but also their embodied energy (16.8-151.1 GJ) and CO_2 emissions (1.6-14.9 ton CO_2-eq). In contrast, the minimum reuse/recycling rates increase environmental burden, and the expansion of unplanned houses is anticipated to cause further urban sprawls and drastic land-use changes by 2020.

INTRODUCTION

One of the obstacles to analyze embodied energy and CO_2 emissions of building materials in developing countries such as in Indonesia is considered to be relatively poor data availability of life cycle building materials from material input to material output (waste) including construction and demolition waste (C&D). The majority of urban housing stocks in Indonesia are unplanned houses. These houses are not designed and constructed in a formal way. Therefore, there is a serious lack of building material inventory data which are required for the analysis of material flow and their embodied energy/CO_2 emissions.

This study analyzes flow of building materials and their embodied energy/CO_2 emissions for urban houses in Indonesia, focusing on unplanned houses, through the material-flow analysis and the input-output (I-O) analysis methods. The actual on-site building measurements were conducted in Jakarta (2012) and Bandung (2011), to investigate building material inventory. The current status of material stock was evaluated. Further, life-cycle material flows, focusing on demolition waste and their embodied energy/CO_2 emissions of urban houses are predicted in different scenarios with various reuse/recycling rates.

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METHODOLOGY

Case study cities and houses

Jakarta and Bandung were selected as case study cities. Jakarta, the capital city, had a population of 9.99 million in 2012 (Jakarta, 2013) while that of Bandung had 2.45 million as of 2012 (Bandung, 2013). Both cities experience hot and humid tropical climates. However, the monthly average temperature in Bandung (22.9-23.9 ºC) is not as high as Jakarta (27.1-28.9 ºC) because of its relatively high altitude. On average, Bandung and Jakarta are located at 791 and 7 m above the sea level, respectively.

In most of the major cities in Indonesia, unplanned houses called '*Kampungs'* account for the largest proportion of the existing housing stocks. These dwellings settled in unplanned and overcrowded urban villages without being provided with basic urban infrastructure and services properly. These unplanned houses accounted for about 74% of the total housing stocks in Jakarta as of 2012 (Jakarta, 2013) and about 89% in the case of Bandung (Bandung, 2013). Moreover, these unplanned houses can be further classified into three house categories based on its construction cost and lot size, namely simple, medium, and luxurious houses (**Figure 1)** having a lifespan of 20, 35, and 50 years, respectively (SNI, 1989).

A total of 297 and 247 residential buildings were investigated in Jakarta and Bandung, respectively (see **Table 1**). As shown, the average household size is about 4-5 persons with a small variation between the three categories for both cities. The monthly average household income was also investigated by a multiple-choice question. As expected, the average income increases with house category from simple to luxurious houses. In general, the average income in Jakarta is slightly higher than that of Bandung. The total floor area also increases with house category in both of the cities. The major building materials used are found to be almost the same in both cities among the above three house categories, though slight differences can be seen in terms of materials for floor and roof.

Current material stock in urban residential buildings

The limitations of data for building, economy and environment in Indonesia make it difficult to clarify the current material stock in urban residential buildings, and to design and implement concrete policies to deal with the issues of C&D waste management. In this study, firstly, we attempt to evaluate a) the current building material stock in urban residential buildings in Jakarta and Bandung at the city level respectively, b) the future demolition waste in unplanned urban houses, and c) the future urban expansion due to demolition of unplanned houses in both of the cities, based on the survey results.

The mathematical equations used to estimate the current material stock for urban houses are described as follows. In this analysis, it is assumed that 1) the number of housing stocks are equal with the number of households determined by number of populations and household size, 2) the income distribution in urban settlement areas of Jakarta and Bandung is the same as the status of whole Jakarta city assuming that low, middle and high income people live in simple, medium and luxurious houses, respectively.

$$TS = \sum_{i}\sum_{j} S_{i.j} \, . \, H_j \tag{1}$$

$$S_{i,j} = \gamma_i \left(PI_{i,j} + MI_{i,j} \right) \tag{2}$$

Figure 1 *Views of sample residential buildings. (a) Simple house; (b) Medium house; (c) Luxurious house*

Table 1 Brief profile of sample houses in Jakarta and Bandung

		Jakarta			Bandung		
		Simple	Medium	Luxurious	Simple	Medium	Luxurious
Sample size		125	115	57	120	99	28
(unplanned/planned)		(125/0)	(75/40)	(29/28)	(120/0)	(99/0)	(28/0)
Household size (persons)		4.3	4.5	5.3	4.7	4.7	5.6
Household income (%)							
< 100 (USD)		4.8	1.7	1.8	10.0	0.0	0.0
100-500		76.8	59.1	19.2	75.8	58.6	7.1
501-1000		16.8	31.3	38.6	14.2	38.4	57.2
>1000		1.6	7.9	40.4	0.0	3.0	35.7
Total floor area (%)							
<50 (m^2)		71.2	9.6	0.0	50.8	6.1	0.0
50 - 99		20.0	51.3	0.0	39.2	34.3	3.6
100 - 300		8.8	36.5	84.2	10.0	58.6	64.3
> 300		0.0	2.6	15.8	0.0	1.0	32.1
Major building materials (%)							
Structure	Concrete	100	100	100	100	100	100
Foundation	Stonene	76	37	22	36	30	13
	Concrete	24	53	78	64	70	87
Floor	Cement	80	0	0	75	0	0
	Ceramic	20	100	100	25	100	100
Walls	Clay brick	100	100	100	98	100	97
	Con-block	0	0	0	2	0	3
Roof	Clay roof	48	79	0	74	94	0
	Concrete roof	0	0	97	0	0	100
	Zinc roof	6	1	0	14	1	0
	Asbestos roof	46	20	3	12	5	0

Source: Building material inventory surveys in Jakarta (2012) and Bandung (2011)

$$H_j = \alpha . \beta_j \frac{TP}{\overline{HS_j}} \tag{3}$$

$$SA_{i,j} = \frac{S_{i,j}}{F_j} \tag{4}$$

Where, *TS*: current total material stock of urban houses (kg), $S_{i,j}$: stock of material *i*, included in the house type *j* (kg/house), subscript *i*: materials shown in **Table 3**, subscript *j*: house type (simple, medium and luxurious) shown in **Figure 1**, and H_j: number of house type *j*, γ_i: the density of material *i* (kg/m^3) shown in **Table 3**, $PI_{i,j}$: volume of primary material *i* input for each type of house for production activities (m^3), $MI_{i,j}$: maintenance volume of material *i* for each type of house (m^3), α: share of population living in urban houses among the total population (Jakarta: 0.74; Bandung: 0.89), β_j: current income distribution (low income (living in simple houses): 0.75, medium income (living in medium houses): 0.20, high income (living in luxurious houses): 0.05) (Mizuho, 2010), *TP*: total population in 2012, $\overline{HS_j}$: averaged household size for each type of houses, $SA_{i,j}$: stock of material *i* per unit gross floor area in house type *j* (kg/m^2), F_j: averaged gross floor area in house type *j* (m^2).

The mathematical equations used to estimate demolition waste from unplanned houses until 2020 are described as follows. In this analysis, we only focus on the demolition waste, generated from the current material stock, estimated by Equation (1). It is assumed that 1) the predicted population of Jakarta and Bandung would be 11.6 and 2.9 million in 2020 (UN, 2011), 2) the share of each type of houses in unplanned residential buildings will be changed in proportion to the significant change in income level; 4% for high, 73% for medium and 23% for low income class (JETRO, 2011), 3) the medium and luxurious houses will not be demolished until 2020, based on the assumption of 2) and buildings' life-spans (i.e. medium houses: 35 years, luxurious houses: 50 years), 4) zero reuse/recycling rates of each material.

$$TW = \sum_i W_{i,simple} . H_{simple} \cdot \eta_{simple} \tag{5}$$

$$\eta_{simple} = \frac{\beta_{simple} - \beta^F_{simple}}{\beta_{simple}} \tag{6}$$

$$WA_{i,simple}=W_{i,simple}/F_{simple} \quad (7)$$

Where, *TW*: total demolition waste from unplanned residential buildings until 2020 (kg), $W_{i,simple}$: demolition waste of material *i* from a simple house (kg) (equal with material stock of simple houses), η_{simple}: demolition ratio of simple houses by 2020, $S_{i,simple}$: stock of material *i*, included in a simple house (kg), β^{F}_{simple}: income distribution of low income group in 2020 (0.23), $WA_{i,simple}$: demolition waste *i* per unit gross floor area in a simple house (kg/m^2), F_{simple}: average gross floor area of a simple house (m^2).

The mathematical equations used to estimate the urban expansion caused by the demolition of unplanned simple houses and the transformation from these simple houses to larger medium houses by 2020 are described as follows. In this analysis, it is assumed that all the demolished simple houses will be reconstructed to be medium houses in the same cities.

$$FE=\left(F_{medium}-F_{simple}\right).H_{simple}.\eta_{simple} \quad (8)$$

Where, *FE*: future urban expansion by 2020 (m^2), F_{medium}: average gross floor area of a medium house (m^2).

Flow of materials and their embodied energy/CO_2 emissions for each type of houses

Secondly, this paper analyzes the per-floor area flow of building materials and their embodied energy/CO_2 emissions for each of the house categories by taking Jakarta for example. Embodied energy/CO_2 emissions of building materials generally includes energy for productions in several phases, including material extraction, production, construction, maintenance, and demolition phases. However, construction and demolition phases were not considered in this paper due to the data unavailability.

The design records such as building drawings are required for the analysis of embodied energy of building materials. These data were available for most of the planned houses and unplanned luxurious houses only. The other houses including most of the unplanned simple and medium houses were not constructed in the formal way (normally constructed by non-professional neighbors) and therefore the required design records could not be obtained. Thus, the actual on-site measurements by using laser-distance meters and tape measures were conducted for unplanned simple and medium houses in order to acquire the data.

Since it was impossible to trace all the production processes for most of the building materials due to the data unavailability, this study adopted the I-O analysis-based method to calculate the embodied energy of materials and estimate their CO_2 emissions, which consistently followed the method described by Nansai et al. (2002). The latest Indonesian nationwide I-O table published in 2005 (Indonesia, 2005) consisting of 175 x 175 sectors was used for calculating the embodied energy/CO_2 emissions, which was measured in the form of primary energy. The detailed procedures of the embodied energy/CO_2 emissions were described in the previous paper (Surahman & Kubota, 2012).

In this analysis, we assess the effects of policy of promoting reused and recycled material use through a scenario analysis. The first scenario (Scenario 1) assumes that both recycling and reuse rates are set to be zero (minimum) and the second scenario (Scenario 2) is designed under the assumption that both reuse and recycling rates for respective building materials are increased to the maximum values (see **Table 2**). The effects of the promotion of reused and recycled building materials use are evaluated through the comparison between two scenarios. The per-house material stock and demolition waste for respective house categories are estimated based on the following equations.

$$W_{i,j}=S_{i,j}\left(1-RU_{i,j}-RC_{i,j}-TR_{i,j}\right) \quad (9)$$

$$WA_{i,j}=W_{i,j}/F_j \quad (10)$$

$$S^R_{i,j}=\gamma_i\left[PI_{i,j}\left(1-RU^p_{i,j}-RC^p_{i,j}\right)+MI_{i,j}\left(1-RU^M_{i,j}-RC^M_{i,j}\right)\right] \quad (11)$$

Where, $W_{i,j}$: demolition waste of material i from a house type j (kg/house), $S_{i,j}$: stock of material i, included in a house type j (kg/house), $RU_{i,j}$: reuse ratio of material i, applied to a house type j (as shown in **Table 2**), $RC_{i,j}$: recycle ratio of material i, applied to a house type j (as shown in **Table 2**), $TR_{i,j}$: treatment ratio of material i, applied to a house type j (assumed to be zero), $WA_{i,j}$: demolition waste i per unit gross floor area of a house type j (kg/m^2), F_j: average gross floor area of a house type j (m^2), $S^R_{i,j}$: Stock of virgin material i in a house type j (kg/house), $RU^p_{i,j}$: reuse ratio of primary input (construction), $RC^p_{i,j}$: recycle ratio of primary input (construction), $RU^M_{i,j}$: reuse ratio of maintenance, $RC^M_{i,j}$: recycle ratio of maintenance. The potential reuse/recycling rates of building materials were studied from some references as shown in **Table 2**.

Table 2 Potential reuse and recycling rates

Materials	Potential rate (%)	
	Reuse	Recycling
Soil	100[a]	0[a]
Stone	100[a]	0[a]
Clay brick	10[a]	90[a]
Concrete brick	0[a]	0[a]
Cement	0	0
Sand	0	0
Steel	0[a]	100[a]
Ceramic tile	0[a]	0[a]
Clear glass	100[a]	100[a]
Wood	50[a]	50[a]
Gypsum	0[b]	100[b]
Paint	0	0
Clay roof	100[a]	100[a]
Concrete roof	100[a]	0[a]
Asbestos roof	0[c]	100[c]
Zinc roof	10[d]	90[d]

a:(Addis, 2006)
b:(Lund-Nielsen, 2014)
c:(CDRA, 2014)
d:(Zinc sheet roofing, 2014)

RESULTS AND DISCUSSION

Current building material stock

This section discusses the current total material stock and future demolition waste in urban houses at the city level in Jakarta and Bandung. The current building material stocks in urban houses in two cities in 2012 were calculated utilizing Equations (1)-(4). **Table 3** shows the composition of the current building material input, including those for maintenance, in the two cities. As shown, overall, the average material quantity per m^2 is 2.14 ton/m^2 in Jakarta and 2.06 ton/m^2 in Bandung. The average material quantity slightly varies among the different house categories in Jakarta and Bandung: 2.26 and 1.88; 2.06 and 2.23, and 2.05 and 2.26 ton/m^2 for simple, medium and luxurious houses, respectively. Overall, stone accounts for the largest percentage in Jakarta and Bandung (32% and 31%), followed by sand (31% and 30%), clay brick (19% and 19%), cement (8% and 8%), etc. The current total material stock in urban houses of Jakarta is measured at 232.0 million ton, while that of Bandung was 77.2 million ton. The difference between the two cities is mainly due to the number of houses difference.

Future demolition waste from unplanned residential buildings until 2020

If both reuse and recycling ratios are assumed to be zero, then the total demolition waste of unplanned houses (i.e. only simple houses) in Jakarta is found to be 41.5 million ton/m^2 until 2020 and all of them go to the landfills (Equations (5)-(7)). Meanwhile, the corresponding amount of waste in Bandung is predicted to be lower (12.6 million ton/m^2) due to less households of simple houses. This scenario will cause the waste to landfills would be very huge, thus results in the overload in the landfills. As a consequence, this scenario anticipates that both Jakarta and Bandung would be forced to construct new landfills to deal with the increased waste in the near future.

Urban sprawl caused by the transformation from simple houses into medium houses

The future demolition of unplanned houses and the transformation of these houses to the larger medium houses by 2020 would cause the further urban expansions in both of the cities: at least, the additional area of 20.0 km^2 is required for the new constructions in Jakarta while the area of 5.7 km^2 is required in Bandung (Equation (8)). These expansions would accelerate urban sprawls.

Scenario analysis: Policy effects of promoting reused/recycled materials use on reduction of building waste and embodied energy/CO_2 emissions

Table 3 Current building material inventory (unit: kg/m^2)

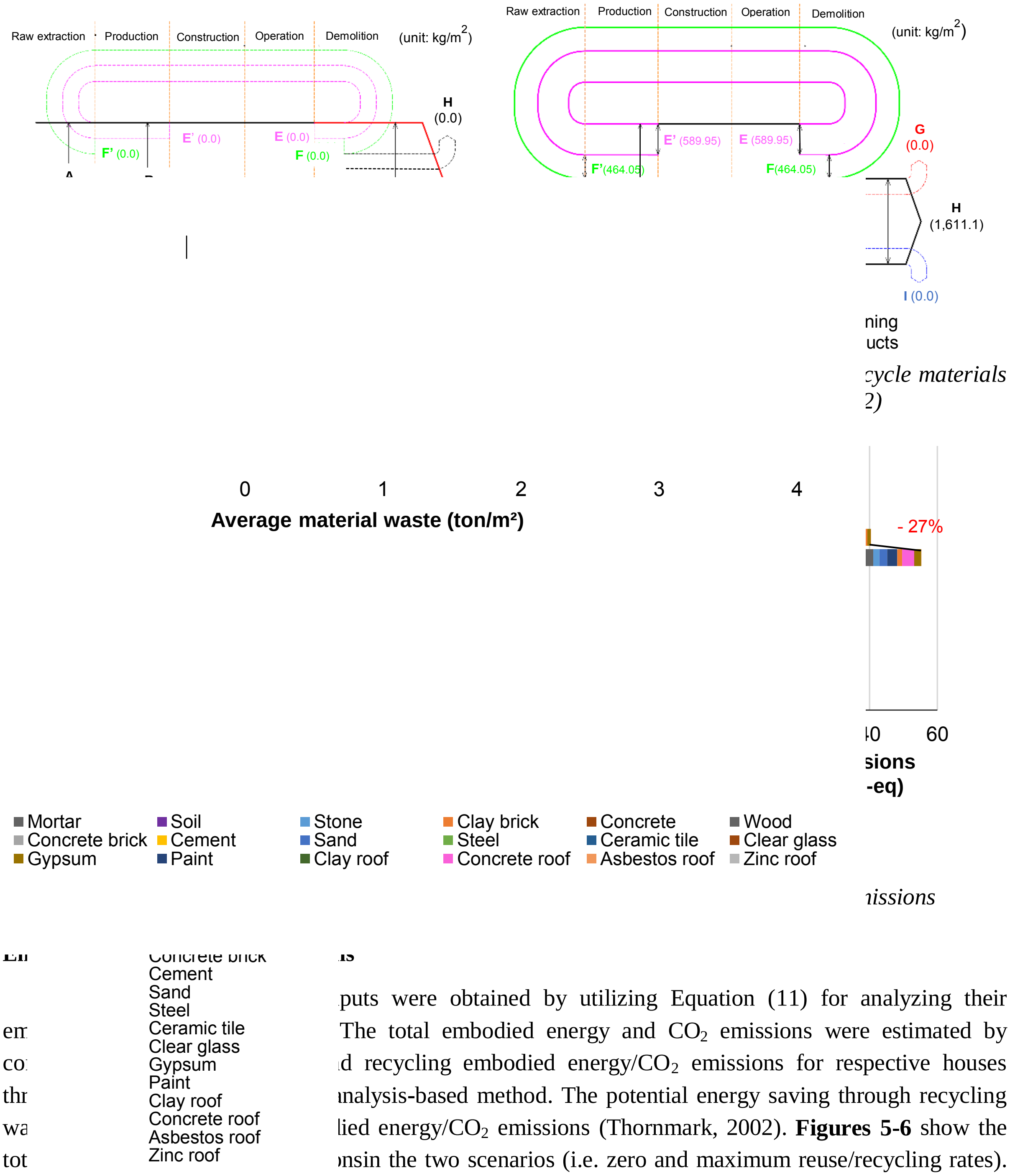
Materials	Density (kg/m^3)*	Simple houses		Medium houses		Luxurious houses		Whole sample	
		Jakarta	Bandung	Jakarta	Bandung	Jakarta	Bandung	Jakarta	Bandung
1. Stone	1,450	729.8	623.1	696.5	682.6	529.0	603.9	678.4	644.7
2. Clay brick	950	494.9	371.7	309.2	414.0	413.3	451.2	407.4	397.7
3. Concrete brick	2,300	0.0	7.5	0.0	0.0	0.0	0.0	0.0	3.6
4. Cement	1,506	142.9	118.8	175.7	185.0	187.4	227.2	164.1	157.6
5. Sand	1,400	717.5	561.0	623.1	674.4	583.8	740.2	655.3	626.8
6. Steel	7,750	16.6	17.3	36.6	37.7	30.5	34.0	27.0	27.4
7. Ceramic tile	2,500	30.8	15.5	33.9	34.2	59.5	77.4	37.5	30.0
8. Clear glass	2,579	0.8	1.2	0.8	1.3	1.3	6.2	0.9	1.8
9. Wood	705	105.0	143.1	131.0	161.5	159.8	43.2	125.6	139.2
10. Gypsum	1,100	0.0	0.3	7.0	1.3	23.0	24.4	7.1	3.4
11. Paint	700	2.0	1.6	5.4	4.4	10.0	12.4	4.9	4.0
12. Clay roof	2,300	16.6	20.7	40.9	30.2	0.0	0.0	22.8	22.2
13. Concrete roof	2,500	0.0	0.0	0.0	0.0	49.9	39.2	9.6	4.4
14. Asbestos roof	2,200	5.6	0.6	2.1	0.3	0.3	0.0	3.2	0.4
15. Zinc roof	3,330	1.2	0.8	0.1	0.1	0.0	0.0	0.5	0.4
Total		2,263.7	1,883.2	2,062.3	2,227.0	2,047.8	2,259.3	2,144.3	2,063.6

*: (SNI, 1989)

Scenario 1; zero reuse and recycling rates. The following section analyze the flow of building materials per-house for each of the house categories by taking Jakarta for example. As described before, we assess the effects of policy of promoting reused and recycled material use through scenario analysis. In this scenario (Scenario 1), the zero reuse/recycling rates are applied to all building materials used for a house. **Figure 2** shows the results of flow analysis for average material input and output of urban houses in Jakarta utilizing zero reuse/recycling rates for whole sample as example. As shown, the total average material inputs including those for maintenance for whole sample ('B' in the **Figure 2**) are derived from **Table 3**. A few materials are imported such as ceramics (37.5 kg/m^2) in the case of luxurious houses. There is no materials reused/recycled for other buildings/products ('E' and 'F') in this scenario. Thus, all materials go to the landfills ('G'). Equations (9)-(10) were used to calculate demolition waste for each of the house categories. The total average waste to landfills is larger than the average material input due to additional waste of soil derived from the surplus soil extracted in the construction phase ('C'), accounting for 2,931.1, 2,521.3, 2,371.5 and 2,665.1 kg/m^2 for simple, medium and luxurious houses as well as whole sample. Overall, mortar accounts for the largest material waste (23%), followed by soil (20%), stone foundation (17%), concrete (16%), clay brick (15%), etc.

Scenario 2; maximum reuse and recycling rates. In this scenario (Scenario 2), we apply the maximum potential for reuse/recycling rates (see **Table 2**). **Figure 3** shows the results of flow analysis of building material input and output for urban houses in Jakarta in Scenario 2 for whole sample. As shown, the total average material input including those for maintenance for respective houses in Jakarta are still the same as those in the Scenario 1 ('B' in the **Figure 3**). However, some materials (589.9 kg/m^2) were reused for other buildings ('E'), including stone (77%), wood (11%), clay brick (7%), etc. Meanwhile, several materials (464.0 kg/m^2) are recycled ('F'), including clay bricks (79%), wood (13%), steel (6%), gypsum (1.5%) and zinc roof (0.5%). There is no material composted/burned ('I'). The rest of materials (soil, mortar, concrete, ceramic and asbestos) are assumed to be reclaimed to other products or infrastructure ('H'). The total waste used for reclamation accounts for 1,715.3, 1,596.3, 1,412.0 and 1,611.1 kg/m^2 for simple, medium and luxurious houses as well as whole sample. Overall, mortar accounts for the largest percentage (39%) followed by soil (32%), concrete (27%), and ceramic tile and asbestos (2%). These materials can not be reused/recycled for other building constructions due to difficulty of separation from mixed materials. Thus, it was found that closed-loop material flow is not enough to fully reclaim building materials and eliminatebuilding material waste to the landfills. Nevertheless, these materials can be reused/recycled by crushing them and used to reclaim for infrastructure such as road and building site. In this case, the total waste to the landfills would become zero.

Figure 4 shows the average material waste of respective houses for both scenarios. As shown maximizing reuse/recycling rates would decrease the average material waste dramatically by 41%, 37% and 40% for simple, medium and luxurious houses, respectively.



cycle materials
2)

issions

En ... ıs

... puts were obtained by utilizing Equation (11) for analyzing their em... The total embodied energy and CO_2 emissions were estimated by co... d recycling embodied energy/CO_2 emissions for respective houses thr... analysis-based method. The potential energy saving through recycling wa... lied energy/CO_2 emissions (Thornmark, 2002). **Figures 5-6** show the tot... onsin the two scenarios (i.e. zero and maximum reuse/recycling rates). The results indicate that the reused/recycled materials reduce not only material waste but also diminish embodied energy/CO_2 emissions. The maximum reuse/recycling ratesare expected to decrease embodied energy by 16.8 (27%), 58.1 (28%), 151.1 (27%) and 58.6 (27%) GJ for simple, medium, luxurious and whole houses, respectively (**Figure 5**). Meanwhile, the reduction patterns of embodied CO_2 emissions are similar with those of embodied energy (**Figure 6**).

The results of the above scenario analysis prove that the promotion of reuse/recycling are important to ensure the building material stocks and to reduce not only material waste but also their embodied energy/CO_2 emissions.

CONCLUSIONS

This study analyzed flow of building materials and their embodied energy/CO_2 emissions for urban houses in Indonesia, focusing especially on unplanned houses. The actual on-site building measurements were conducted in Jakarta (n=297) and Bandung (n=247) to investigate building material inventory.

- Overall, the average material quantity per m^2 was 2.14 ton/m^2 in Jakarta and 2.06 ton/m^2 in Bandung.

The average material quantity slightly varied among the different house categories in Jakarta/Bandung: 2.26/1.88, 2.06/2.23 and 2.05/2.26 ton/m^2 for simple, medium and luxurious houses, respectively. On average, the stone accounted for the largest percentage for all houses (32%/31%), followed by sand (31%/30%), clay brick (19%/19%), cement (8%/8%), etc.

- If both reuse and recycling rates are assumed to be zero, then the total demolition waste of unplanned simple houses in Jakarta was found to be 41.5 million ton/m^2 until 2020 and the corresponding waste in Bandung is predicted to be lower (12.6 million ton/m^2). All of them go to the landfills. Moreover, the transformation of these simple houses to the larger medium houses by 2020 would cause further urban expansion in both of the cities: at least, the additional area of 20.0 km^2 is required for the new construction in Jakarta, while the area of 5.7 km^2 is required in Bandung.
- A scenario analysis was conducted for Jakarta to assess the effects of policy of promoting reused and recycled material use. The two scenarios with the zero and maximum reuse/recycling rates were compared in the analysis. The results showed that maximizing reuse/recycling rates would decrease the average material waste dramatically by 37% to 41%. The promotion of reuse/recycling were proved to reduce embodied energy/CO_2 emissions of building materials effectively (27% to 28%).
- The lack of policies for promoting 3Rs (reduce, reuse and recycling) specifically target C&D waste (Indonesia, 2008) at the national level is considered one of the crucial problems in Indonesia.
- The increase in larger landed houses would directly result in the rapid horizontal expansions of the cities, thus accelerates urban sprawls. Provision of mid-to-high-rise apartments to the growing middle class in the cities would be one of the effective housing policies for already crowded Indonesian cities.

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Urban Climate mapping of an Institutional Campus in Hot-Humid Climate using GIS

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ABSTR ACT

Urbanization modifies the built form to a greater extent and exerts extreme heat stress due to the urban heat island (UHI) effect in hot and humid climates. Sathyabama University - an institutional campus in Chennai experiences a UHI intensity of 6°C to 10°C during the day. The students in the campus often use the outdoor spaces for their interactions and discussions. This paper aims to map the urban climate in an institutional campus and analyze the outdoor comfort conditions. The urban climate mapping is done through field measurements and comfort conditions are analyzed through a questionnaire survey. The field measurements include the recording of hourly air temperature and humidity data using HOBO U20 datalogger on a hot summer day. Isopleths are derived using ArcGIS and the heat and cool pockets in the campus are identified. The questionnaire survey records the thermal sensation of the students and is compared with the isopleths to arrive at a climate sensitive design. The survey results can aid in improving the outdoor comfort through increase in vegetation cover in the campus.

INTRODUCTION

Urbanization modifies the built form to a greater extent and exerts extreme heat stress due to the urban heat island (UHI) effect in hot and humid climates. Also the urban land uses and the related activities increase the urban air temperatures. The increased temperatures in urban areas results in the formation of heat pockets and are termed the “Urban Heat Island” (UHI) (Landsberg 1981). This thermal difference between urban and rural areas determines the intensity of heat island. The rate of cooling of open spaces when compared to that of the dense built up spaces, contributes significantly to the intensity of UHI (Givoni 1998).

Studies on climate change due to urbanization have gained momentum, and have become the main focus of research in the recent past. Urban climates are distinguished from those of less built-up areas by differences in air temperature, humidity, wind speed and amount of precipitation. These differences are mainly due to the alteration of natural surfaces with highly reflective parking lots, concrete masses, asphalt roads etc., resulting in higher absorption of solar radiation, thereby affecting the thermal environment. Oke (1981) states that the rate of cooling of urban areas at the micro level depends on two parameters; the street geometry and the sky view factor. Todhunter (1990) explains that at the canyon layer, urban geometry plays an important role in defining the spatial and temporal distribution of the UHI compared to surface materials. Saito et al (1990) found that even small green areas can reduce the temperatures by 3°C, when compared to the built up surfaces in the city of Kumamoto. Akbari et al (1992) identified that large number of trees and urban parks can reduce local air temperatures by 0.5°C to 5.1°C. Unger et al (1999, 2001) found that there exists a strong relationship between urban thermal excess and land use features and built up density in Szeged, Hungary. Johansson and Emmanuel (2006) analyzed the influence of street canyon geometry on the outdoor thermal comfort in Colombo and identified that the differences in air temperatures were higher during the day, especially in the afternoons when compared to the night and a maximum difference of 7°C was found between sites. Amirtham et al (2009) investigated the land cover changes due to urbanization in the city of Chennai from 1991 to 2000 and found a significant increase in hot spots in the city mainly attributed to the increase in the urban built up. Rose (2010) found the existence of UHI in Chennai city through the study of historic climate records from meteorological stations and also found a statistically significant increasing trend in the discomfort due to urbanization.

Thermal comfort indices combine two or more parameters into a single factor. Spagolo and de Dear (2003) found the outdoor thermal comfort index OUT SET* in the subtropical Sydney as 26.2^0C and that of the indoor SET* as 24^0C. Taib (2010) in the assessment of thermal comfort parameters in landscape gardens in high rise buildings identified significant variation in air temperature, humidity, wind speed and radiation; but the survey on users perception revealed differences only in lighting level and wind speed. Also the behavioural adaptations of users in urban open spaces in Taiwan revealed that the attendance in urban parks was influenced by sun and thermal conditions (Lin et al 2013). Yang et al (2013) found that the neutral operative temperature and preferred temperature as 28.7°C and 26.5°C in Singapore. And the study also found that people in outdoors generally have a higher tolerance level to comfort conditions when compared to indoors especially in the tropics. The study also suggested that the combination of lower density spaces with higher building heights would reduce the sky view factor value and the incoming solar radiation thus improving the outdoor thermal comfort.

Chennai, a tropical city characterized by high temperatures and humidities, suffers extensively due to the urban heat island effect which affects the outdoor thermal comfort conditions significantly. Therefore, this study aims at the enhancement of outdoor thermal comfort conditions, through urban climate mapping in an institutional campus in Chennai.

AREA OF STUDY

Sathyabama University is an institutional campus in the suburbs of Chennai experiencing hot humid climate (Figure 1a). The maximum air temperatures during summer (May and June) varies between 38°C and 42°C and the minimum air temperatures during winter (December and January) varies between 18°C and 20°C. The average monthly relative humidity ranges from 63% (June) to 80% (November) and the vapour pressure varies between 22.6hpa and 32hpa. The institution houses several academic blocks of varying street geometry. Five different locations in the campus were selected considering various parameters such as the percentage of vegetation, orientation of streets and canyon geometry (H/W ratio). The thermal properties of the built surfaces were similar in all locations. Figure 1b shows the measurement locations in the campus.

a) b)

Figure 1 a) Sathyabama University Campus, Chennai b) Measurement locations in the academic zone

1 2 3 4 5

Figure 2 Images of Measurement locations (1-5)

The data loggers placed at five strategic locations within the academic zone were based on the percentage of vegetation, orientation of streets and canyon geometry as shown in figure 2. Logger 1, 3 & 5 is placed in the N-S orientated streets with canyon geometry of 1, 2 and 1.67 respectively. Logger 2 & 4 has been positioned in the E-W streets with canyon geometry of 0.5 each.

METHODOLOGY

The air temperature and relative humidity data were measured continuously on an hourly basis using HOBO dataloggers (HOBO U20 Temp/RH) in the selected locations. The wind speed and the cloud cover data from the Nungambakkam Meteorological station were used for the study. The urban climate mapping of the campus was derived using ArcGIS. Temperature isopleths on a typical summer day are derived for 02:00 hrs, 06:00hrs, 10:00hrs, 14:00hrs, 18:00hrs & 22:00hrs. The analysis of the daytime and night time isopleths reveals the temperature distribution pattern in the campus. Also, a questionnaire survey on thermal sensation in the selected locations was conducted to study the subjective response of students to the outdoor thermal environment during daytime. The sample questionnaire used for survey is shown in appendix 1. The subjective response of the respondents and the temperature isopleths during daytime were compared to identify the appropriate built geometry for a thermally comfortable environment.

RESULTS AND DISCUSSION

Analysis of the Daytime and Night time Isopleths

The campus has various functional spaces and the present study is confined to the academic zone where most of the student interaction takes place, thus highlighting the need of a thermally comfortable outdoor environment. Table 1 shows the ambient air temperature on a typical summer day and Table 2 shows the recorded relative humidity.

Table 1. Daily Air Temperatures at Various Locations

Location / Logger	Longitude x	Latitude y	Temperatures in ^{o}C at 4 hrs interval 02:00 AM	06:00 AM	10:00 AM	02:00 PM	06:00 PM	10:00 PM
1	80.22159	12.8744	30.04	28.34	32.58	32.82	30.96	30.23
2	80.221	12.87434	30.22	28.69	33.92	35.56	31.79	30.61
3	80.22076	12.874	30.10	28.47	32.40	32.18	31.02	30.27
4	80.2205	12.87363	29.87	28.17	32.20	32.54	30.74	30.04
5	80.21962	12.87409	30.12	30.20	31.13	31.18	29.62	30.26

Table 2. Daily Relative Humidity at Various Locations

Location / Logger	Longitude x	Latitude y	Relative Humidity in % at 4 hrs interval 02:00 AM	06:00 AM	10:00 AM	02:00 PM	06:00 PM	10:00 PM
1	80.22159	12.8744	73.43	73.67	68.97	69.80	78.08	82.91
2	80.221	12.87434	72.95	72.89	64.57	61.66	75.25	81.74
3	80.22076	12.874	74.51	73.15	68.78	71.87	77.52	82.63
4	80.2205	12.87363	75.53	75.24	70.13	71.64	79.55	84.63
5	80.21962	12.87409	72.99	69.40	79.44	76.92	84.44	82.21

Air temperatures and relative humidity recorded on a typical summer day has been mapped at 02:00 hrs, 06:00hrs, 10:00hrs, 14:00hrs, 18:00hrs & 22:00hrs with a four hour interval. The isopleths derived using ArcGIS is shown in Figure 3 which revealed a distinct temperature difference between the streets with greenery and non green spaces. The canyon geometry and the street orientation also had a significant impact on the temperatures.

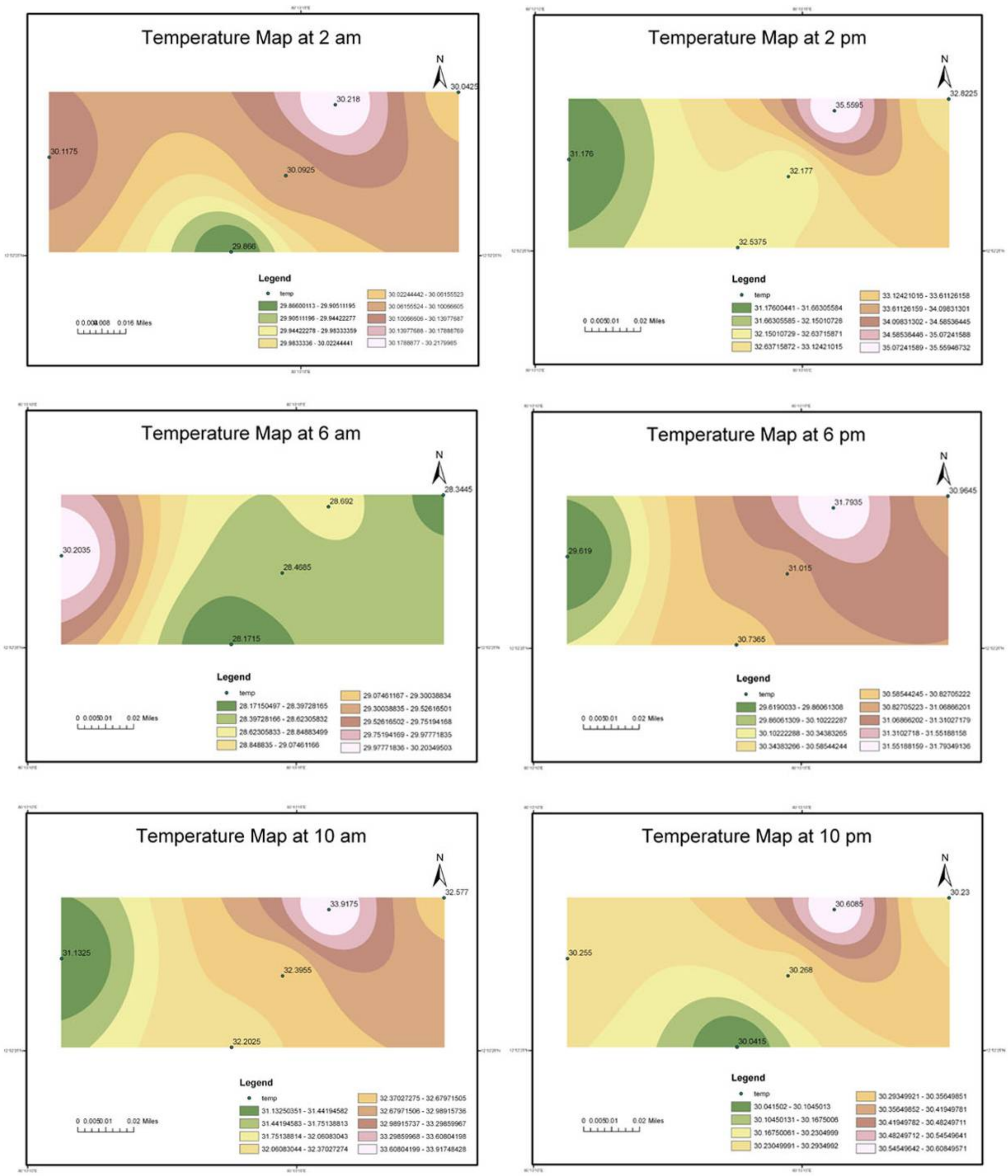

Figure 3 Temperature isopleths in the academic zone of the institutional campus at 4 hrs interval

At 6:00 am locations 1 & 4 experienced the lowest temperature and location 5 recorded the maximum temperature with a difference of 2.03^{0}C. Location 5 situated in the N-S oriented street has a higher canyon geometry of 1.67, attributed to the increase in temperature. The narrow street geometry reduces the reradiation of longwave radiation back to the sky and also because of the differential heating of the surfaces. Determining the mean radiant temperature (MRT) by measuring the long wave and short wave radiation (VDI 1994, Ali-Toudert 2005) from different directions would be more effective in calculating the outdoor comfort conditions more precisely but has not been done in this study. At 10:00hrs Location 5 experienced the lowest temperature and maximum temperature was recorded at location 2 with the temperature difference of 2.8^{0}C. The presence of vegetation at location 5 shaded the streets and also reduced the incoming solar radiation. At 2.00 PM, when the maximum temperatures are recorded, location 5 experienced the lowest temperature when compared to the other locations with a maximum heat island intensity of 4.40^{0}C. At 6.00 PM during sunset location 2 experienced the maximum temperature of 31.8^{0}C. The temperature isopleths at 6.00 PM shows clearly the existence of UHI around location 2 where the E-W orientated streets, the street geometry and non greenery play a vital role. The concrete roads, the wider streets with the reflected radiation from the abutting buildings increased the air temperatures at location 2. The cool spots throughout the day is identified at location 5 followed by location 4 which is attributed to the presence of greenery. Thus the study reinforces the fact that existence of vegetation and trees reduces the ambient air temperatures significantly. During night time, the temperature remains almost the same in all locations at 10.00 PM and 2:00 AM. Thus improvement of daytime outdoor comfort is essential in hot humid climates like Chennai.

During daytime, the relative humidity varies from 61.65% to 84.63% and the maximum humidity is recorded at location 5, due to the presence of vegetation and the minimum humidity recorded at location 2. At night, maximum humidity is recorded at location 4 and minimum at location 5. During night, the ambient air temperature at location 5 is high as the trees reduce the sky view factor thereby restricting the reradiation to the sky. The elevated air temperatures at location 5 reduce the humidity during night as shown in Figure 4.

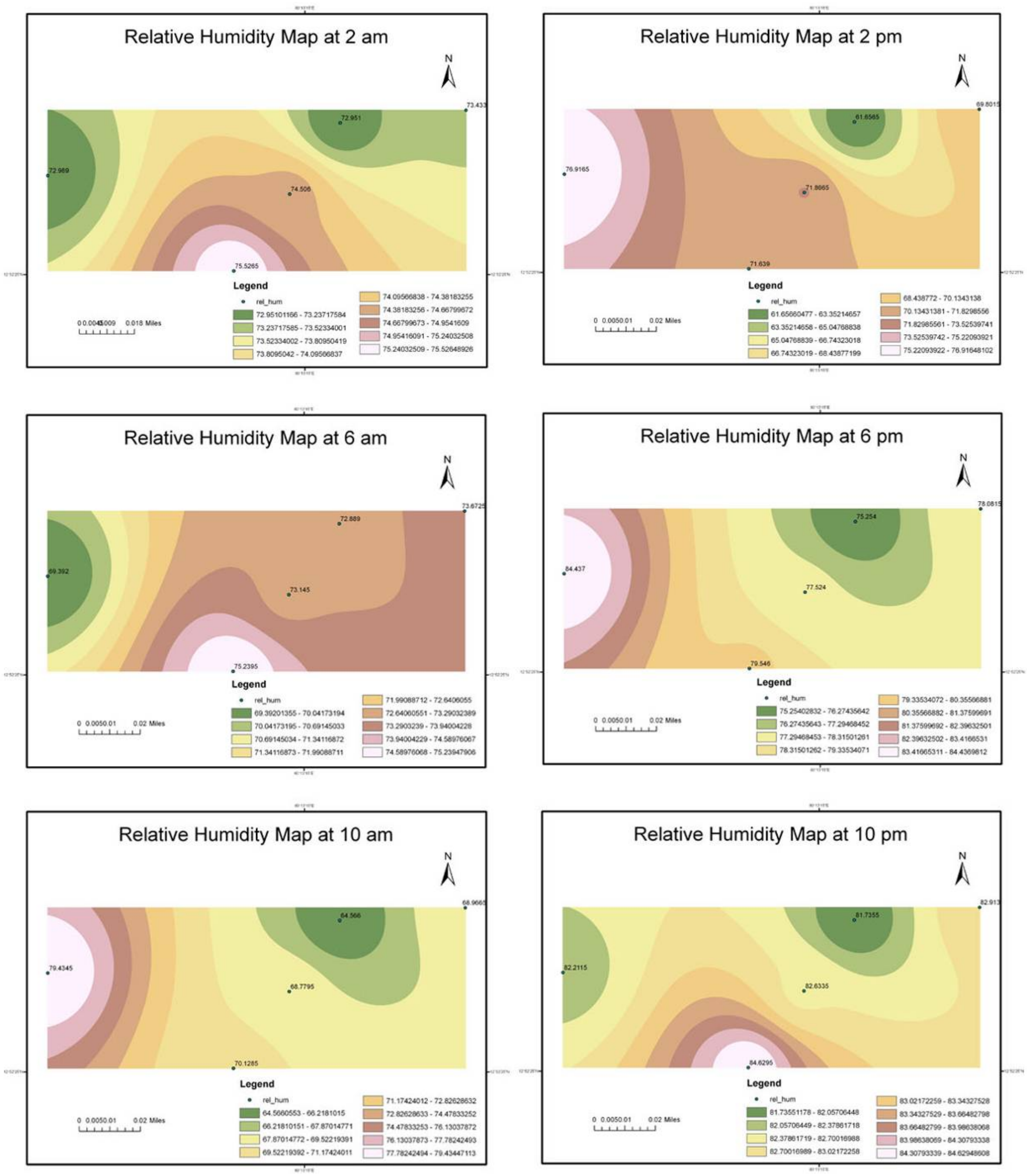

Figure 4 Relative humidity Isopleths of in the academic zone of the institutional campus at 4 hrs interval.

Analysis of Questionnaire Survey

The results of questionnaire survey in the selected locations are compared with the isopleths to comprehend the thermal sensation of the users in the academic zone. Figure 5 show the thermal perception of human with respect to the thermal sensation, feeling of comfort, satisfactory level of comfort in the place and the overall conditions of acceptance. The result on thermal sensation revealed that the respondents felt the heat and were almost tolerable at location 5 due to vegetation shading and none of the other locations were comfortable. At locations 1 & 2, the thermal perception the respondents were too warm due to the absence of shading and the reflective nature of the abutting buildings.

The users were not satisfied with the ambient air temperature in the campus. The dissatisfaction is more at locations 1 & 2 and satisfaction rates are high at locations 3 & 5 due to the presence of greenery. The overall conditions inside the campus are acceptable for the users near the locations 3 & 5 due to the N-S orientation and the presence of vegetation at location 5, thus providing a comfortable environment.

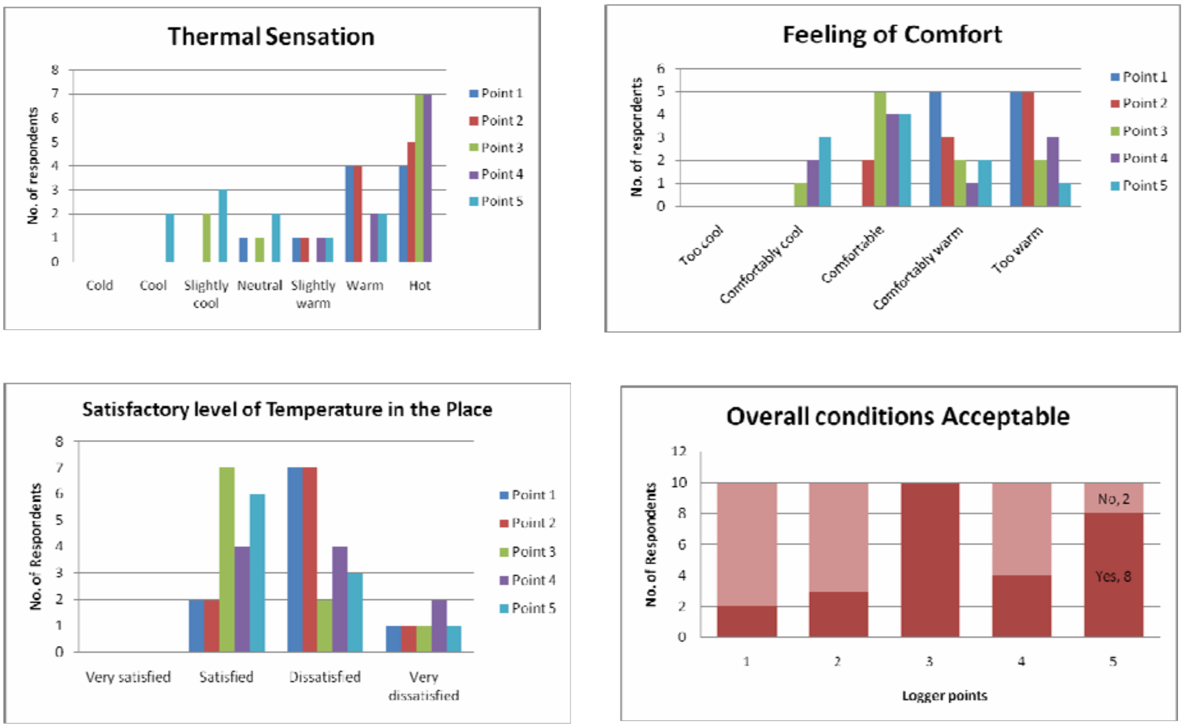

Figure 5 Bar charts showing the survey results of the respondents in the campus at various logger locations.

CONCLUSION

The study revealed that heat pocket exists in the campus at location 2 in the academic zone both during day and night. Temperature difference as high as 4.4^{0}C exists during the peak time of 2:00 PM. The radiation of heat from the buildings and pavement and the street orientation increases the ambient air temperature at location 2. Also, the absence of vegetation at location 2 accelerates the air temperature thus attributing to the heat stress. The isopelths highlights the importance of the greenery in the built form which helps in the reduction of ambient temperatures. At locations 4 and 5, the existing greenery keeps the place comfortable when compared to other locations and the respondents expressed the feel of comfort. The subjective response of students on the comfort levels of outdoor thermal environment during daytime also revealed the heat stress at location 2. Increasing the shading through vegetation in the campus and the internal shading of buildings as in location 3 with a height to width ratio of 2 can provide better daytime comfort.

NOMENCLATURE

UHI	=	Urban Heat Island
H / W	=	Height to width ratio
Street Canyon	=	Street Geometry
OUT SET*	=	Outdoor Standard Effective Temperature in degree Celsius
SET*	=	Standard Effective Temperature in degree Celsius
MRT	=	Mean Radiant Temperature

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APPENDIX 1

STUDY ON THERMAL COMFORT IN AN INSTITUTIONAL BUILDING

I like your participation in answering this questionnaire based on your thermal comfort, the inputs from this survey helps us to analyze occupants comfort level in this institutional building.

Age:	**Sex:**	**Time:**
Clothing:	**Are you under Fan:**	(Yes/ No/ Partial)

Please Tick (   ) the suitable bubble against the various scales:

1.Orientation of the Location:

North	South	East	West

2.Vegetation Index of the Location:

No vegetation	Sparse Vegetation	Existence of Shrubs	Existence of Trees

3.Thermal Sensation:

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

4.Feeling of Comfort:

Too cool	Comfortably cool	Comfortable	Comfortably warm	Too warm

5.Satisfactory level of temperature in the place:

Very satisfied	Satisfied	Dissatisfied	Very dissatisfied

6.Level of Air movement should be:

Lesser	As it is	More

7.Level of Humidity should be:

Lesser	As it is	More

8.How would you like to be :

Cooler	As it is	Warmer

9.Are the overall conditions acceptable:

Yes	No

Passive Cooling Techniques in an Outdoor Space and its Effects on the Indoor Climate

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ABSTRACT

Passive cooling techniques such as evapotranspiration from plants and watering are effective for ameliorating outdoor microclimates in hot summer. Natural ventilation also helps to make an indoor thermal environment more comfortable. However, in Japan's humid and hot summer climate, there is a limited opportunity to gain a cooling effect by ventilation. Therefore, this study focuses on passive cooling techniques to improve the outdoor microclimate near the window of a residential building to achieve a cooling effect by ventilation despite the hot climate and to reduce the demand for cooling energy. Measurements were conducted two cases during one summer on a target building located in a residential area with a window which located at the floor level to help natural ventilation. The first case had no additional plants in front of the window, and the second case did. The results show that when the ground and in front of the window were kept wet by watering and shaded, the radiant temperature, measured by a thermal infrared camera, was about 1−7 °C lower than the outside air temperature at the 3p.m. Consequently, the air temperature near the window was 2−4 °C lower than the outside air temperature. However, due to watering and evapotranspirating of plants, absolute humidity increased 2 g/kg' in the after adding plants case in front of the window. Although the indoor wind velocity came to a tenth of the roof wind speed, because of adding plants, inflow rate through the window was not changed. Therefore, the cooling potential was created at the outdoor space by applying the passive cooling techniques. When this cooling potential was used by ventilation, the sensible heat flux decreased 200–300 W through the daytime, and latent heat flux increased 100–300 W at the nighttime.

INTRODUCTION

Natural ventilation is known to be one of the most effective passive methods for creating a comfortable indoor climate and to conserve energy consumption. The outdoor microclimate, including air temperature, humidity, wind velocity, wind direction and solar radiation, has a direct impact on the effectiveness of ventilation for cooling. Fig. 1(b) shows the average, maximum, and minimum monthly temperatures from April to October in Tokyo from 2000 to 2013(Obeseved by Japan Meteorological Agency). Maximum temperatures in midsummer (July and August) are higer than 30 °C. Therefore, Tokyo's air temperatures in July and August are too high to utilize outside air for natural ventilation. Many studies show that maximum suitable outdoor air temperature for natural ventilation is between 28 and 30 °C (Givoni, 1992; Habara et al., 2012). Therefore, not only the indoor thermal environment but also the outdoor microclimate around the house must be improved in order to utilize natural ventilation in the midsummer season.

Many passive cooling techniques and designs have been developed and studied. Solar shading (Nikoofard et al., 2011; Berry et al., 2013) by structures and trees reduces the amount of solar radiation in the summer season, and contributes to a decrease in a building's surface temperature and energy demands. The transpiration of trees can prevent increases in the air temperature around trees (Umeda et al., 2006). Atmospheric radiation cooling is a phenomenon by which heat is lost by the emission of longwave radiation toward the sky at night-time. Nocturnal ventilation cooling (Givoni, 1991) with cold storage lowers the daytime temperature and makes possible to reduce the length of the periods requiring the operation of additional cooling systems. Each of these examples is individual approaches to improve and evaluate indoor, and outdoor microclimates. However, there has been little research about evaluating the change of the indoor thermal environment utilizing multiple passive cooling systems.

This study aims to introduce the passive cooling systems at an outdoor space and to evaluate its effect on the indoor thermal climate utilizing the natural ventilation by measurement. We measured the cooling effects of plants and water retentive blocks as well as the negative influences of increased humidity and air flow decrement by analyzing the microclimatic parameters around the actual house quantitatively. Then, we focused on changing the indoor thermal climate by introducing cooled air through an open window which helps the natural ventilation located at the floor level.

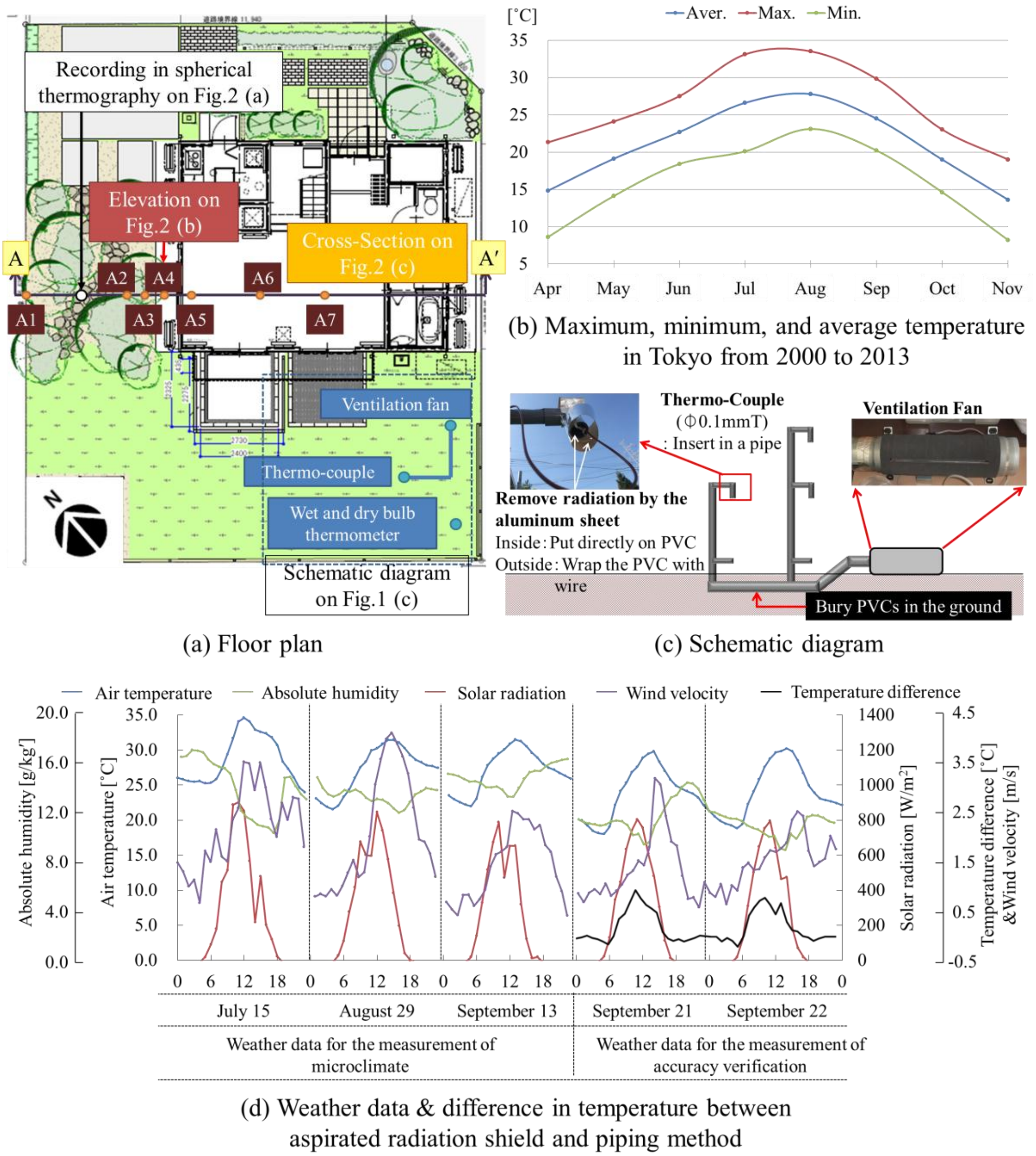


Figure 1 Outlines of measurement

MEASUREMENT DETAILS FOR HORIZONTAL AND VERTICAL AIR TEMPERATURE DISTRIBUTION

In order to adequately investigate the space where cooled air is created and where the air flows into building, the spatial distribution of the microclimatic parameters must be measured minutely. In this section, we propose a method for measuring the air temperature using polyvinyl chloride (PVC) piping with fan-aspirated ventilation. We then, describe the measurement method and the improvements made to the microclimate with plants and watering.

Measurement Method

When the measurement of air temperature and humidity is conducted at the outdoor space, solar and other radiation factors in the immediate surroundings must be removed. To do so, an aspirated radiation shield is often used. However, as the aspirated radiation shield is large, it is not suitable for measuring vertical and multipoint temperature distributions. We used PVC pipes (Φ13 mm) and ventilation fans (air volume: 75 m^3/h, static pressure in the pipe: 100 Pa) to measure outdoor air temperature and humidity accurately. Each of the measurement points was connected by piping. The measurement sensors were a thermo-couple (Φ0.1 mm type T thermo-couple) and a resistance change type humidity sensor (TDK, CHS-UPS), which were inserted into a pipe. When taking measurements using the PVC pipe, to prevent overestimation due to radiation from the surroundings, the pipe diameter was controlled to maintain sufficient wind speed (3 to 5m/s) at each measurement point. Ventilation fans were then connected to PVC pipes. In addition, the PVC pipes at the measurement point were screened two times with an aluminum sheet (Fig.1(c)).

The measurement results using this proposed PVC pipe method were compared with forced ventilation thermometer with aspirated radiation shield to verify accuracy. The measurement comparisons were made at intervals of 10 s for two days (September 21 and 22, 2013). Fig. 1(d) shows the differences in air temperatures between the PVC pipe method and the forced ventilation thermometer. Air temperature is almost identical at night when there is no solar radiation and a temperature error maximum of +0.9 °C exists at daytime when insolation is elevated. The results show an accuracy of +0.6 °C with a 95% confidence interval.

Measurement Conditions

Table 1. Details of the measurements of the effect of plants and water retentive blocks

	July 15(Case 1)	August 29(Case 2)
Condition	Trees (height 0.8 – 3 m) were 0.7 m away from the window.	Additional planting, water retentive blocks were added.
Watering	Automatic watering at 7a.m, 11a.m, 3p.m, and 7p.m by mist sprayer for 5 min.	Continuous watering from 7 a.m. to 7 p.m. by hosepipe.
Photographs		

Measurements of the microclimate around the building were made on July 15 and August 29, 2013. The measurement conditions are detailed in Table 1. In the July measurement, there were trees 0.7 m away from the window. There was nothing except the PVC pipe for measurement in front of the window. In the August measurement, we added additional plants and water retentive blocks as passive cooling materials in front of the window. Moreover, the watering method and times were changed to wet more surfaces of the leaf and block. In addition, vertical measurement points were added in front of the window to measure in detail the cooling effect of the additional plants. The indoor air temperature was measured near the window (A5 in Fig. 1(a)) and in the living room (A6, A7 in Fig. 1(a)).

EFFECTIVENESS OF EVAPORATIVE COOLING IN CASE OF UTILIZING PLANTS AND WATER RETENTIVE BLOCKS NEAR THE OPEN WINDOW

In order to analyze the cooling effect around the house, we used the abovementioned method to measure the effects of the passive cooling system applied outside the house. This section focuses on the following factors: improvement in surface temperature, decrease in air temperature, increase in humidity, and wind velocity decrement.

The Improvement in Surface Temperature

Thermal infrared images of the area in front of the window were obtained using spherical thermography (Asano, 1996). Fig. 2(a) shows an image obtained at 3p.m on August 29. The surface temperature of the wall was over 40 °C due to the afternoon insolation. However, the surface temperature of leaves and blocks in front of the window (shown in the inside of white rectangle on this thermal image) was 1 °C to 7 °C lower than the air temperature. Therefore, we have confirmed the cooling potential created by additional plants, watering, and shade near the window. In particular, the surface temperature of the water retentive blocks under the window is about 8 °C lower than the air temperature. However, we must also address how to introduce this cooled air into the indoor area.

The Decrease in Air Temperature

Fig. 2(b) shows the vertical air temperature distribution in front of the window (A4, Fig. 1(a)). While the vertical distribution was almost similar as that before the additional planting (Case 1), a temperature discrepancy of 2 to 4 °C occurred after the additional planting (Case 2) during the daytime.

An A – A′ cross-section (Fig. 1(a)) of the air temperature distribution can be seen in Fig. 2(c). At noon, the air temperature near the window (A4) was 1.5°C to 2 °C lower than the air temperature outside the target area (A1). At 3p.m, the air temperature near the window (A4) showed a decrease of about 2 °C in comparison with the A1 air temperature in the case 2 measurement, while the air temperature near the window (A4) was 1 °C higher than the A1 air temperature in the case 1 measurement. This difference occurred because the afternoon solar radiation was blocked and evapotranspirating was more conducted by the additional plants, so the A4 air temperature was lower on August 29. In addition, the indoor and outdoor air temperature difference was just 1 °C at night-time. It is clear that the decrease in the nighttime indoor air temperature was due to ventilation.

The Increase in Humidity

Fig. 2(d) shows the absolute humidity at each of the measurement points (A1, A4, A5, and A6 of Fig. 1(a)). Before the additional planting (left side of Fig. 2(d)), humidity decreased as the daytime air temperature increase. However, with the addintional plants and watering, the humidity of the indoor space (A6) on August 29 had increased to 14 g/kg′, while the outdoor (A1) humidity was about 10 g/kg′. Thus, even when the initial indoor humidity was higher than the outdoor humidity, the humidity of the indoor space in the case 2 was shown to be 2 g/kg′ higher than the outdoor measurement.

The Wind Velocity Decrement

To analyze the wind flow frequency, we conducted a test on September 13(A5) using a 3D supersonic anemometer. The wind direction on the date of the main measurement and that on September 13 are shown in the left side of Fig. 2(e). The July 15 wind direction (before the additional planting) was a little different than the September measurement. However, wind direction data for the August 29 and September 13 cases, both occurring after the additional planting, are almost identical. Graph, right side of Fig. 2(e), shows the inflow and outflow frequency at the window. In day-time, the inflow rate was recorded to be 40 % on average after additional plants.

Fig. 2(f) shows the decrement of wind speed after the additional planting, both in the velocity at the roof and near the window. However, the difference of the inside velocity in the before and after the additional planting cases near the window was approximately 0.2 m/s. Although wind speed decreased, the results shows that cooled air flowed to the inside area through the window. Thus, the cooled air created in front of the window did effectively replace the indoor air.

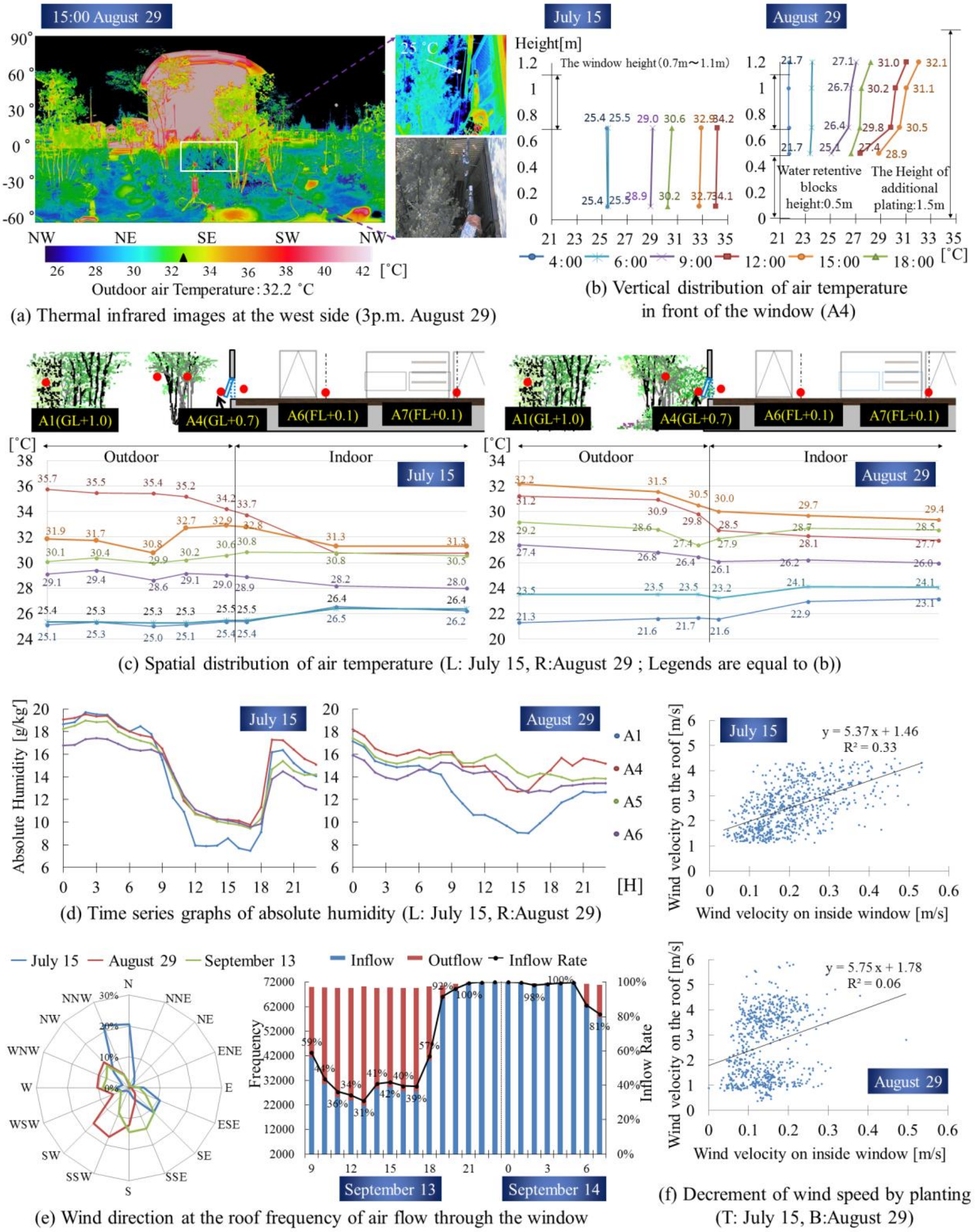


Figure 2 Spatial distributions of the microclimates

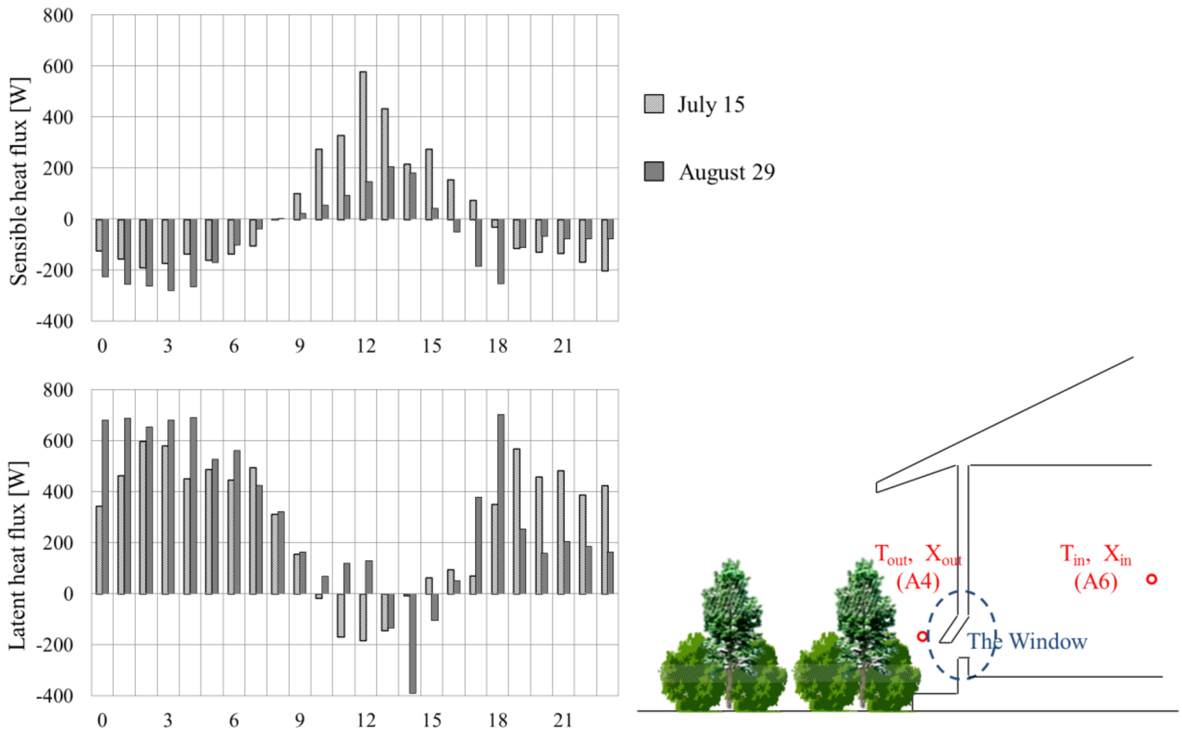
Evaluation of the Passive Cooling Effect by Heat Flux

In order to evaluate the effect of the passive cooling techniques at the outdoor space to the indoor space, we calculated the sensible and latent heat fluxes using the following equations. A comparison of these fluxes is shown in Fig. 3.

$$\boxed{\text{Sensible heat flux}} \qquad q_s[W] = C_p \cdot \rho \cdot V \cdot (T_{out} - T_{in}) \cdot 1000$$

$$\boxed{\text{Latent heat flux}} \qquad q_L[W] = \gamma_\gamma \cdot \rho \cdot V \cdot (X_{out} - X_{in}) \cdot 1000$$

The August 29 sensible heat flux decreased maximum 200–300 W compared with that on July 15 in the daytime. Furthermore, the length of time when the sensible heat flux was above zero diminished from 9 to 4 h. In the midnight, 100 W or more of sensible heat was removed from the indoors to the outdoors through the window on August 29. Conversely, the August 29 latent heat flux at nighttime was higher by 100–300 W than that of July 15. However, although latent heat flux of August 29 was high, the indoor humidity was lower than that on July 15. It means humidity increases due to the plants and water retentive blocks, however, its effect on the thermal comfort of indoor is small because the absolute humidity is influenced by the weather conditions.



(a) Sensible and latent heat fluxes(A4-A6)

(b) Cross-section of target building

Figure 3 Estimation of the passive cooling effect near the window

CONCLUSION

By locating plants and water retentive blocks in front of a window, we created a cooling potential at the outdoor space. We then quantitatively evaluated the influence of the cooling potential by evaporative cooling using the plants and water retentive blocks on the thermal environment of the indoor space by ventilation through the window.

1) To measure in detail the microclimate around the building, air temperature measurements were taken using a PVC piping method. The accuracy of this method verified to be +0.6 °C with a 95% confidence interval.

2) A decrease in the air temperature was observed 2 to 4 °C by passive cooling due to solar shading and evaporative cooling.

3) Although the wall surface temperature was over 40 °C at 3p.m due to the afternoon sun, the surface temperature of leaves and blocks with watering and shading in front of the window was 1 °C to 7 °C lower than the surrounding air temperature.

4) Due to the presence of additional plants near the window, the inside wind speed came to a tenth of the roof wind speed.

5) The length of time when the sensible heat flux was above zero diminished from 9 to 4 h.

The results show that application of passive cooling techniques can enhance the microclimate at the outdoor space, create a cooling potential around the building in the daytime. And there was little effect of the increase in humidity on the indoor climates by the passive cooling techniques. In the next study, we are going to measure the effect of nighttime ventilation with cold storage at floor and to evaluate how it can control the increase in the indoor daytime air temperature.

NOMENCLATURE

Cp : Specific heat at constant pressure of air (=1.006[kJ/kg・°C])

ρ : Density of air (=1.2[kg/m^3])

V: Air Volume [m^3/s] (=H0.5 [m] × W0.7 [m] × 2 × Wind velocity [m/s])

T_{out} : Air Temperature at A4 [˚C]

T_{in} : Air Temperature at A6 [˚C]

X_{out} : Absolute humidity at A4 [kg/kg (DA)]

X_{in} : Absolute humidity at A6 [kg/kg (DA)]

γ : Latent heat of vaporization (=2430 [kJ/kg])

Refer to Fig.3 (b) where the detail points are (A4, A6).

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Session 6C : Energy and resource mapping, management & improvements

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The Effects of Energy-efficient Buildings on Facilities Management and Usability with a Focus on Passive House Schools in Norway

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ABSTRACT

The objective of this paper is to improve the understanding of energy-efficient buildngs' management and usability. The intention is to contribute to overall improvements in the energy efficiency of built environments through an integrated approach to considerations of building design, facilities management, and user perspectives. An overview of the development of highly energy-efficient buildings with a focus on passive house school buildings is presented. The passive house standard is defined considering a newly developed and recently implemented passive house standard for non-residential buildings in Norway. The effects of energy-efficient buildings on facilities management and usability are comparatively studied with a focus on Norway's first and one of the newest passive house schools. Finally, the benefits and risks, the need to develop highly energy-efficient buildings, and the management and user interaction are discussed and summarized.

1 INTRODUCTION

Energy-efficiency of the built environment is of high importance all over Europe and on international level. Since it has become common knowledge that buildings contribute to 40% of the total energy consumption in European countries much effort has been input into improving existing building stocks and further improvements are still needed (EU, 2012). While the energy-efficiency improvement of the built environment lasts for some time, the development of management concepts and a better understanding of the buildings users' behavior merits more attention. Such integrative understanding would help to achieve buildings' projected performance and close the research gap recently highlighted by Bordass and Leaman (2013, p. 1): "Research into building performance continues to reveal that even the best buildings often fail to perform as anticipated." Consideration of the effects of interaction between building design, management, and use would also contribute to a better understanding of the processes or mechanisms that occur within building stocks. Buildings themselves do not consume energy, but rather the users or mechanisms within them create the demand for energy (Sartori, Wachenfeldt, & Hestnes, 2009). The development of innovative technology and its implementation in highly energy-efficient buildings such as passive houses and nearly zero-energy buildings is driven by policy and legislation, including for example Directive 2012/27/EU on energy efficiency. This energy efficiency directive states requirements regarding the improvement of energy efficiency in the public building sector: "Member States shall encourage public bodies, including at regional and local levels, with due regard to their respective competences and administrative set-up, to follow the exemplary role of their central governments to purchase only products, services and buildings with high energy-efficiency performance" (EU, 2012, p. 15). If the implementation of Directive 2012/27/EU is accepted as performance-based norm, it might also increase the demand for facilities management competence with reference Joanna Eley's vision—published before the implementation process of the EU's Energy Performance of Buildings Directive (EPBD) had begun——that "In the fullness of time, if performance-based building and regulations are accepted as the norm, facility managers will become key players in assessment" (Eley, 2001, p. 5).

The decission to study passive house schools is based on the fact that school buildings form the largest group of public buildings and belong to one of the three largest groups of non-residential buildings in Europe. Non-residential buildings are more complex and less studied than residential buildings. The European non-residential building stock includes mainly wholesale and retail buildings (28%) a large amount of office buildings (23%), and as third largest group the educational buildings with a 17% share in terms of total floor area. The remainder of the non-residential building stock comprises the following categories: hotels and restaurants (11%), hospitals (7%), sport facilities (4%), and other buildings (11%) (Laustsen et al., 2011, p. 8). The overall building stock of all EU27 countries, Norway, and Switzerland has been assessed as having c.25 billion m^2 of useful floor area, of which 25% are non-residential buildings and 75% residential buildings, used by more than 500 million people (Laustsen et al., 2011). Norway, the northernmost country in Europe, currently has a population of 5 million people. The country's existing building stock is estimated as having a gross floor area of 325 million m^2 divided between residential buildings (210 million m^2; 64%) and non-residential buildings (115 million m^2; 36%) (Haugen, 2008). Sartori et al. (2009, p. 1614) state: "Energy demand in the building stock in Norway represents about 40% of the final energy consumption, of which 22% goes to the residential sector and 18% to the non-residential sector." Norway has traditionally used a high amount of electrical energy for heating buildings. Due to the country's dependence on hydroelectricity, buildings in Norway have some of the lowest CO2 performances found in Europe (Laustsen et al., 2011). However, due to limited supplies of hydropower, the increasing demand for electricity causes problems, as stated by Halse (2005, p. 1) almost ten years ago: "consumption of electricity is reaching a level where additional growth will have to be covered by traditional non-renewable resources."

2 METHODOLOGY

The research is mainly based on the conduction of case studies. Case studies are considered as a most suitable approach to develop insights in a high level of complexity in its real-life context. The passive house school examples have been selected based on a thourogly conducted state of the art literature review. The development and implementation of passive house school design has been studied on international level (PHI., n.d., NS3710, 2012) and the management and usability with a special focus on Norway (THOMSEN, J., BERKER, T., HAUGE, Å. L., DENIZOU, K., WÅGØ, S., & JERKØ, S., 2013). The information utilized for the first case study, Åsveien School, is based on a project which has been conducted in cooperation with a public Real Estate and Facilities Management department. In autumn 2013 a group of master studends were involved in workshops, and the conduction of experts' interviews and site visits. The information about the second passive house school case study is based on published scientific conference papers (DOKKA, T. H., & ANDERSEN, G. (2012), JERKØ, S., MYSEN, M., HOMB, A., NERSVEEN, J., NILSEN, S., BLOM, P., & CHRISTOPHERSEN, J. (2006), research reports (THUNSHELLE, K., & LAPPEGARD HAUGE, Å. (2012) and interviews and site visits conducted by the author in 2014.

3 THE STATE OF THE ART

The passive house concept has been described earlier as "buildings, for which thermal comfort (ISO7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions –without the need for additional recirculation of air" (PHI, n.d.). The basic principles of passive houses were summarized in five categories: (1) thermal insulation, (2) passive house windows, (3) ventilation with heat recovery, (4) airtightness, and (5) thermal bridge free design (Feist, 2013). This concept was mainly applied on passive houses, which were built as private homes, with the main objective of reducing the amount of energy used for heating. This was achieved through the construction of highly insulated, compact and airtight buildings with ventilation systems with heat recovery and special passive house windows.

In Norway, the passive house concept was further developed into a passive house standard for non-residential buildings (NS3701, 2012). Lexow and Dokka (2012, p. 5) state: “Standards Norway is the first member of the European Committee for Standardization (CEN) to have a national standard with criteria for Passive Houses covering all building categories defined in the national building code.” The standard specifies requirements for different non-residential building types, according to the Norwegian climate, building construction method, and architectural context. All buildings in Norway certified as energy-efficient conforming to either passive house or low-energy standards. The certification includes the minimum requirements for heat losses, cooling demand, heating demand, energy supply, and technical infrastructure as elements of a building’s design, components, and systems, as well as air tightness of the building envelope.

A conceptual structure for the description of passive houses can be summarized as follows: (1) General information providing some general information about the building (building type, gross floor area, location, and year of construction); (2) Winter heat insulation described by the compactness of the building form and quality of the thermal insulation of the building envelope (ground floor, outer walls, and roof), regarding the passive house requirement of reduced heat losses for transmission and infiltration; (3) Summer heat protection described by the quality of summer heat protection and how zero energy supply for cooling is achieved considering the orientation of rooms, heat storage, solar shading; (4) Energy supply considering the main energy sources and the technical systems of heating, domestic hot water, ventilation, lighting, technical equipment, and cooling; and (5) Windows described as such and as building parts, and with consideration of entrance doors.

4 PASSIVE HOUSE SCHOOLS IN NORWAY AND SELECTION OF CASE STUDIES

The passive house concept has been studied in Norway since the year 2000. In 2005, Norwegian researchers recognized a growing interest in the passive house concept in relation to low-energy housing. At that time mainly residential passive house buildings such as single-family houses were constructed. However, a growing interest in the passive house concept was identified. Halse (2005, p. 4) stated: “Passive houses and low-energy housing is on the verge of market breakthrough.” Five years later, in 2010, the first Norwegian passive house school building, Marienlyst School in Drammen, was taken into use (Dokka & Andersen, 2012; Thomsen et al., 2013; Thunshelle & Lappegard Hauge, 2012).

The number of high-energy efficient non-residential buildings is expected to increase continuously up to 2020 in Norway. (Enova, 2012, p. 15). The Norwegian Government is supporting municipalities in the development and construction of climate and environmentally friendly pilot projects under the programs “Framtidens by” (Cities of the Future) and “FutureBuilt.” As part of the program “Framtidens by”, city municipalities are encouraged to share ideas on climate-friendly city development in cooperation with the business sector, the regions, and the Government. “Framtidens by” is scheduled to run for six years (2008–2014) and the 13 largest cities in Norway involved in the program are: Bergen, Bærum, Drammen, Fredrikstad, Kristiansand, Oslo, Porsgrunn, Sandnes, Sarpsborg, Skien, Stavanger, Tromsø, and Trondheim (Government.no, 2011).

The “FutureBuilt” program is scheduled to run for ten years (2010–2020) and will support the realization of 50 projects contributing to the reduction of greenhouse gas emissions and a good city environment. Projects may also include urban areas or individual buildings. The cooperating partners in “FutureBuilt” are four municipal authorities (Oslo, Bærum, Asker, and Drammen), the Ministry of Local Government and Modernisation, the Norwegian State Housing Bank (Husbank), the Norwegian energy national fund (Enova), the national fund to reduce greenhouse gas (GHG) emissions from transport (Transnova), the National Office of Building Technology and Administration, the Green Building Alliance, and the National Association of Norwegian Architects (NAL). In 2014, the project documentation included six school projects (Table 1) within a total of 30 pilot projects: urban areas, schools, kindergartens, office buildings, cultural centers, and housing projects (futurebuilt.no, 2014).

Table 1. The development of passive house schools in Norway sorted by the year of construction (Newest, Oldest), (Source: futurebuilt.no, 2014, "Framtidens by"* and/or "FutureBuilt)

School building	School name (Norwegian name), location, year of construction	Energy-efficiency and FM relevant key figures	School type of use and user relevant key figures
	Åsveien skole,* Trondheim, 2013–2015	Gross floor area (GFA): 8836 m^2 Energy demand: 61 $kWh/m^2/year$	Primary school with 630 students, and autism center for 20 students
	Veitvet skole, Oslo, 2011–2015	GFA: 8789 m^2 Energy demand: 62 $kWh/m^2/year$	Primary and lower secondary school for Class 1 to 10, class with multiple-use hall, 840 students (school and multipurpose hall)
	Nye Gran skole, Oslo, 2010–2015	GFA: 6079 m^2 Energy demand: 61 $kWh/m^2/year$	Lower secondary school, 540 students, 65 man-labor years, 80 users
	Frydenhaug skole, Drammen, 2011–2014	GFA: 5795 $m^{2,}$ Energy demand data unavailable	Intermunicipal primary school and resource center for students with disabilities 100 students, 110 man-labor years
	Bjørnsletta skole, Oslo, 2010–2014	GFA: 9677 m^2 Energy demand: 64 $kWh/m^2/year$	Primary and lower secondary school, 790 students, special department for 12 students with autism
	Stasjonsfjellet skole, Oslo, 2010–2014	GFA: 3663 m^2 Energy demand: 74 $kWh/m^2/year$	Lower secondary school 390 students, 35 full-time equivalent (FTE) man-labor years
	Søreide primary school, Bergen,* 2011–2013	GFA: 7910 m^2 Energy demand: 43 kWh $m^2/year$	Primary school
	Heistad skole, Porsgrunn, 2008–2012	Energy demand (NS-3031): 37 $kWh/m^2/year$	Primary school, special department for 14 severely disabled students

	Marienlyst skole, Drammen, 2008–2010	6454 m^2 GFA Energy demand: 70 kWh/m^2/year	510 students, 95man-labor years c.12 m^2/student

5 SIMILARITIES AND CONTRASTS BETWEEN THE OLDEST AND NEWEST PASSIVE HOUSE SCHOOLS

Åsveien School in Trondheim is the newest passive house school in Norway. The building has been under construction since July 2013 and will be finished and taken into use in 2015, five years after the completion and start of operation of Norway’s first passive house school Marienlyst School in Drammen in 2010.

5.1 Comparison of the school buildings’ energy performance

In Trondheim, Åsveien School, which will be a passive house primary school has been under construction since 2013 and will be finished and taken into management and use in 2015. The project, including the main building of the primary school for 630 students and a department for 20 students with autism, has a total gross floor area of 8836 m^2. In addition, a multipurpose hall with a gross floor area of 2336 m^2 is under construction on the same site (Hasenmüller, 2013).

Marienlyst School, a lower secondary school is located in the centre of Drammen, a city c.40 km west of Oslo. The school is adjacent to a sports arena (Marienlyst idrettspark) and a public swimming pool (Drammensbad). The school has a heated floor area of c.6450 m^2. The school has a compact building form comprising three stories. Due to natural changes in the ground level on site, the first floor is partially buried and includes a large auditorium for the whole school, as well as locker rooms, rooms for special functions, and a library. The second floor has a community area with a café, workplaces for teachers, administration offices, and rooms for special functions. The third floor consists mainly of compact student areas and group rooms. The architectural design is characterized by a clear and simple building shape with much variation in architectural expression, form, and use of materials (Dokka & Andersen, 2012, Hahn, 2013).

Table 1 shows a comparison of the simulated energy demand of both Åsveien School and Marienlyst School, built according to Norwegian standards (NS3700, NS3701, and NS3031). The measured energy consumption of Marienlyst School for the academic year 2011–2012 is also shown.

Table 2. Building Energy Performance (kWh/m^2/year) of Two Passive House Schools in Norway (Dokka and Andersen, 2012, Hasenmüller, 2013)

Energy use categories	Åsveien School simulated energy budget	Marienlyst School simulated energy budget	Marienlyst School measured energy consumption
Room heating	9	12.8	13.7
Ventilation heating	4.4	0.6	4.1
Domestic hot water	10	10.1	3.1
Fans and pumps	12.7	10.8	12.8
Lighting	8.3	15.5	13.3
Technical equip.	8.8	13.3	13.9
Cooling	0.7	0	0
Total net energy demand	53.9	62.9	60.9

5.2 Effects on facilities management

The general understanding of facilities management in Norway is that it refers to the European standard, and it includes all traditional roles and methods related to the administration, operation, maintenance, and development of buildings, and service provision for building users. A triangular symbol is often used to visualize the interaction between the three key players, namely the building owner, building user, and building manager. However, in everyday practice many actors interact and thus there are also strategic, tactical, and operational levels in the functioning of buildings. For example, the school janitor may be described as an actor at an operational level (Haugen, 2003, p. 14). Some Norwegian public authorities are continuing with the traditional administration, operation, and maintenance (*forvaltning, drift, vedlikehold* (FDV)) focus, whereas others have adopted the FM approach in full. A variety of organizational models and service provision concepts exist, including the client-supplier-model, and different approaches to in-house service provision, outsourcing, or out-tasking (Haugen, 2003, 2008; Junghans & Olsson, 2014; Novakovic et al., 2012).

Marienlyst School is one of 21 school buildings that together account for 300,000 m^2 of public buildings owned by Drammen Municipality. Drammen Eiendom KF, the real estate and FM department of Drammen Municipality, represents the owner of the school building and is responsible for the buildings' management and operation as well as the management of facilities service provision. The general field of responsibility of the real estate and FM department includes operation, maintenance, modernization, new building development and realization, purchasing, selling, leasing, and renting.

Energy management is a subdomain of FM, and integrates all relevant facilities services to ensure that "Client demand for utilities (technical infrastructure) is satisfied by services resulting in a comfortable climate, lighting/shading, electrical power, water and gas" (EN 15221-1, 2007). The main area of responsibility is visible in the operational and utilization phase of a building. Regular monitoring of the power consumption, benchmark analyses, and identification of savings potentials and their implementation are essential working areas in energy management (Junghans, 2012).

The users of Marienlyst School experienced some problems with their school building that could be associated with the commissioning of the building and fine-tuning of automatic systems in the first year of occupation. The researchers highlighted the following issues (Thunshelle & Lappegard Hauge 2012):
(1) Temperature: Cold temperatures during the first winter, in 2010, especially in the mornings, were reported in interviews. A lack of supply from the district heating network was indicated as the main reason together with the fact that the winter of 2010 was particularly cold. One year later, the problems were not mentioned, but many of the interviewed students responded that some rooms could be cold or have varying temperatures. It was also pointed out in the interviews that some rooms could be hot and airless in summer months. The latter problem was connected with the use of sunscreens (see "Solar shading" below).
(2) Ventilation and air flow: The interviewees indicated that there were problems with air pressure conditions in the building. Doors were either slamming or were too heavy to open easily, or they remained open and emitted a peeping sound, probably due to the ventilation system. [Comment from the author: Probably the maintenance staff would have known why the doors made a peeping sound? Perhaps the doors were also fire doors that needed to be kept closed when not in use, and therefore emitted a warning sound if they were accidentally left open.] There were some complaints about the heavy and bad quality air in the small auditorium and small group rooms in core areas on the third floor, and thus the ventilation in these areas needed to be investigated further. The described problems indicated a need to examine the balancing and sizing of the ventilation units in the school.
(3) Solar shading: The interviews and responses to the researchers' questionnaire documented that the automatic shading and lighting did not work properly. Heat from the sun was also sometimes problematic. Teachers often wanted opportunities to override the solar shading systems in order to have more control over room temperatures. In addition, it appeared that the electric lighting that turned off automatically (controlled by light motion sensors) should have been fine-tuned so that it was more sensitive to movement than it was when the evaluation was conducted.

5.3 Effects on usability

Norwegian researchers have developed a systematic approach for the assessment of school learning environments. The main criteria evaluated are structured in the following three categories, with increasing degrees of complexity:

1. Evaluation of the Indoor climate with focus on five subcategories: thermal- (temperature quality), atmospheric- (air quality), acoustic- (sound quality), actinic- (light and radiation), and mechanical environment (vibrations)
2. Evaluation of the indoor environment, which includes: indoor climate, together with two subcategories, namely the aesthetic environment (visual impact) and the psychosocial environment (interpersonal relationships)
3. Evaluation of the physical environment, which includes the evaluation of the indoor environment (mentioned in point 2 above), together with four subcategories: the building's suitability for the use (operations and functionality), its suitability for the users (universal design), the user density (area efficiency, m^2/student, and volume/student), and usage time (duration of room usage, over time) (Jerkø et al., 2006).

Teachers, other employees, and students at Marienlyst School needed more information about how the building automation system worked and could be adjusted. Especially the solar shading, lighting, and temperature regulation needed to be better understood. Thus, there is a need for cooperation between the users and management staff of new schools when the final adjustments to all technical systems are being made according to user demand. The passive house building at Marienlyst School has improved awareness of the environmentally friendly profile of the school. Moreover, the teachers indicated that they would have liked more information about the passive house concept to communicate to their students (Thunshelle & Lappegard Hauge 2012).

6 CONCLUSION

In this paper, the complexity of energy-efficiency improvements in built environments has been studied with focus on passive house schools in Norway. The intention has been to improve the understanding of passive houses and how they are managed and used. A structure for the description of passive house examples has been developed based on the definition of the passive house concept and the Norwegian passive house standard (NS3701). Nine Norwegian passive house school projects have been identified through publically accessible sources. Marienlyst School in Drammen and Åsveien School in Trondheim, respectively the first and most recent passive house schools, were selected as study cases. The building energy performance of both schools has been compared on the basis of the simulated energy budgets, and the measured energy consumption of Marienlyst School has been reported. The definition of facilities management in Norway and an approach for usability evaluation have been shown to structure the effects of facilities management and usability. In the studied cases, the effects of FM referred to energy management and the janitor as a key actor at an operational level were indentified. The paper reveals that the main aspects of usability are related to the provision of a good indoor climate quality and communication with and feedback from the building user.

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The Energy Master Plan: Transition to self-sufficient city regions by means of an approach to local energy potentials

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ABSTRACT

City regions and metropolitan areas form the scale on which the battle for will be won or lost, and the level at which cities can become resilient and even self-sufficient. A master plan for a sustainable energy system for city regions is not a luxury anymore.

An energy master plan will be based on incremental steps of transition. The approach needs to start with the charting of energy sources, sinks and unused potentials of a studied area. Herein the method of Energy Potential Mapping can play an essential role. The next step deals with the identification of demand reduction possibilities in the existing built environment – new construction can already be zero energy. Differences in simultaneous discrepancies between supply and demand can be bridged by synergetic systems, heat exchange, cascading and intermediate storage of energy. Finally the remaining demand needs to be solved with renewable energy, inside the city as well as in its environs, which become ever more indispensable to the modern metropolis.

In the energy master plan EPM deals with the identification of supply and demand, supports the finding - in place and time - of energy potentials from sun to magma, helps the discovery of simultaneous mismatches, surpluses and shortages, and helps determine the effect on the urban climate. Mapping is done in 3D, soon to be 4D, including the time factor (diurnal differences, seasonal differences, long-term developments).

Since 2005 Energy Potential Mapping has been developed at TU Delft. It has gained international scientific standing. The advanced 3D method has been used for sustainable energy plans and currently forms the basis for making Dutch regions energy-neutral, in cooperation with local stakeholders. The full paper will describe the Energy Master Plan approach and Energy Potential Mapping method, illustrated by cases executed so far.

1. INTRODUCTION

Sustainable development will become a question of climate adaptation and mitigation (IPCC, 2014) on the one hand and the lasting availability of resources on the other (Haas, 2013). Of these resources, after the basic needs for human survival – oxygen, drinking water and food – energy is the most quintessential element for human society. Without energy no element of civilization can be continued: buildings cannot be operated anymore, drinking water cannot be pumped around or poured into bottles, food cannot be transported from farms to cities and people will be limited again by travel distances they can cover by foot, bike or horse. Energy is the fuel of modern society – the end of energy will be the end of cities as we know them.

One might argue that present-day economy has built in sufficient safety and security for the continued provision of energy and all other needs, but over the past few decades various occurrences have demonstrated that cities are very vulnerable to hampering supplies. For instance, technical failures and black-outs have rendered power plants out of operation (e.g. New York City, USA, 2006), airplane accidents have cut major high-voltage lines supplying urbanized areas (e.g. the central river region, Netherlands, 2009), natural disasters have led to the destruction of power plants (e.g. Fukushima, Japan, 2010), politically driven decisions have blocked supplies (e.g. Russia versus Ukraine, 2009 and 2014), terrorist attacks have damaged energy infrastructure (e.g. Russia, 2010), and – more 'friendly' as we know it – market price mechanisms have influenced supplies in various ways (e.g. the Gulf War effects, late 1990s).

In the past most city regions used to be self-supporting entities: think of the Mesopotamian cities, Greek City states, yet also European mediaeval regional centres. Resource cycles used to be closed, meaning that all food, water, energy and materials came from the direct environs and waste products were reused in that same vicinity. Where this evolved out of balance, cities collapsed – think of the ancient Egyptian centres and Mayan cities on the Yucatán peninsula in Mexico. We are now in an era where none of the world's cities is self-sufficient. Globalisation has made cities strongly dependent on supplies from elsewhere, and wastes are also treated in places mostly not known to citizens. As described with the examples of hampering supplies of energy, this implies cities presently are very vulnerable to failures in the system.

The inevitable conclusion of the previous is that for a secure, sustainable future, cities need to become resilient. A greater extent of self-sufficiency will help to achieve this. Supported by historic examples, city regions and metropolitan areas are still the most suited level at which sources and sinks can be solved locally. Therefore these form the scale on which the battle for sustainability will be won or lost, and the level at which cities can become resilient and even self-sufficient. However, how are we going to transform existing cities or emerging and growing metropolitan areas, with their non-sustainable systems, to sustainable ones?

A master plan for a sustainable energy system for city regions is not a luxury anymore. There is not one single solution that will provide the answer; enforced by successful examples this paper discusses one approach that may help.

2. ENERGY MASTER PLAN

For the research presented the authors based themselves on existing urban regions. Handling an existing city must entail a stepped approach, since commencing with an integrated design from scratch is impossible. The proposed Energy Master Plan will therefore be based on incremental steps of transition.

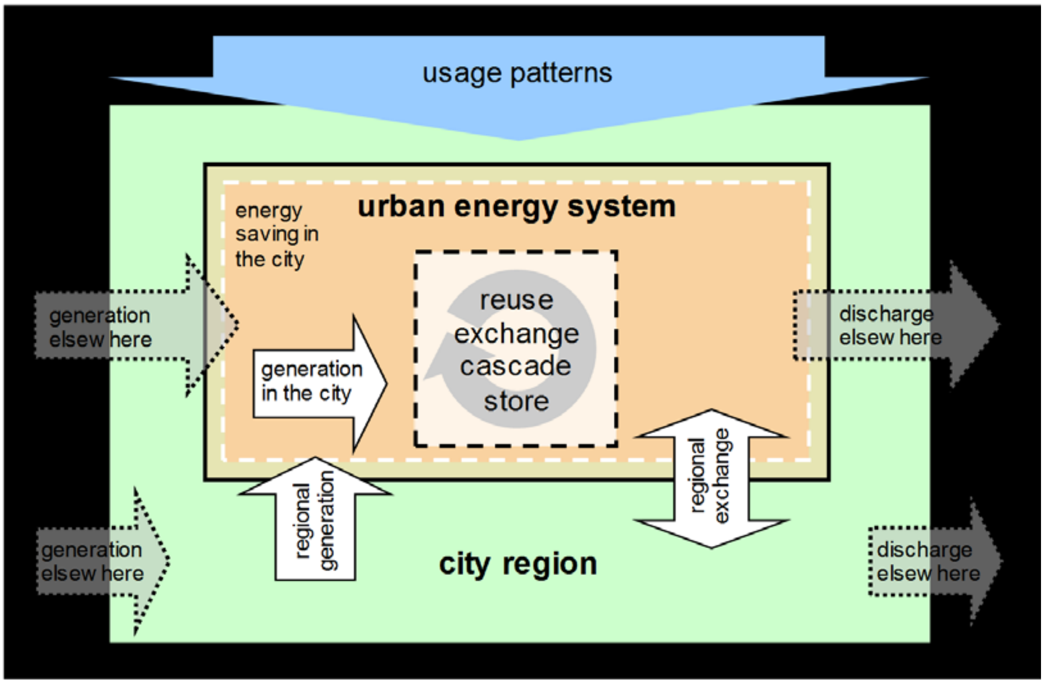

Figure 1 *Graphic depiction of the Energy Master Plan for self-sufficient cities (Dobbelsteen, 2012a)*

A quintessential basis for an effective approach to cities is formed by proper knowledge of the city's use patterns of energy: data are needed of energy consumption, production of energy and residual waste flows, to as much detail as possible. So the Energy Master Plan starts with the charting of energy consumption figures, sources, sinks and unused potentials of the studied area. Herein the method of Energy Potential Mapping discussed further on can play an essential role.

A first real step deals with the identification of demand reduction possibilities in the existing built environment. Every part of the energy demand you can reduce, means avoidance of required energy production; so it is a first step to self-sufficiency. New to be constructed buildings can already be net zero energy. Ambitious cities had better enforce that new development actually is energy-neutral, because all new non-sustainable developments add up to the already present problem. The greatest potential in most cities however lies in an improvement of the existing stock of real estate, so a meticulous analysis of the potential of energy saving in different districts and neighbourhoods, depending on the urban typology and architecture, will help make a leap forward.

A second step deals with the potential that lies within differences between supply and demand. In temperate climates with both heat and cold demands simultaneous discrepancies in demand and supply can be bridged by synergetic systems, heat exchange, cascading and intermediate storage of energy. Heat grids are already well-known in colder climates; these are usually based on high-caloric heat sources, often originating from fossil energy sources. There are however other options (as studied, for instance in the European FP7 projects CELSIUS and City-zen). Lower-temperature grids can also be deployed in order to optimize the exchange of heat (Dobbelsteen et al., 2012b), and cold grids can serve cities with a substantial demand for cooling. Energy can also be reaped from other resources' wastes, such as waste water or waste material. In these cases processing is most likely to be arranged outside the city borders. So inter-exchanging with the region becomes important here.

Finally, the remaining demand needs to be fulfilled with renewable energy, to be generated inside the city but in terms of quantity most logically outside the urbanised area, which has more space to allocate conversion techniques to produce electricity or heat. We should acknowledge that with the fossil reserves depleting, the world's energy supply needs to come from its surface ever more. This entails a competition with other forms of land use: agriculture, nature, recreation, building sites, etc. Therefore we need to become very considerate about the use of land around cities, for which Energy Potential Mapping (EPM) is a proven means to provide insight in the energy potentials locally available inside and outside the city. Taking into account the enormous quantity of energy a modern city consumes, every acre of urbanised area needs at least an acre of energy-productive land. The city's environs therefore become ever more indispensable to the modern metropolis.

3. ENERGY POTENTIAL MAPPING

As discussed, present-day urban energy systems largely rely on a controlled supply, capable of delivering high-exergy electricity and heat when and where required. Dimensioning of energy systems is mostly defined by peak demands. As the many renewable sources from sun to magma are fluctuating and/or take on a lower exergetic form (for example low-temperature heat), knowing both the spatial and temporal behaviour of urban energy demand and supply are paramount to shaping an Energy Master Plan.

The method of Energy Potential Mapping (Dobbelsteen et al., 2011; Broersma et al., 2013a), developed since 2005 at the chair of Climate Design & Sustainability at the Delft University of Technology and having gained international standing, aims to provide quantitative insight in the when and the where of these, visualising both mismatches, surpluses and shortages. The advanced 3D method (soon to be 4D, by detailed geospatial inclusion of the time factor) has been used for sustainable energy plans and forms the basis for making Dutch regions energy-neutral, in cooperation with local stakeholders, by providing them with a palet of possibilities with which they can choose and design appropriate, robust and long term sustainable measures.

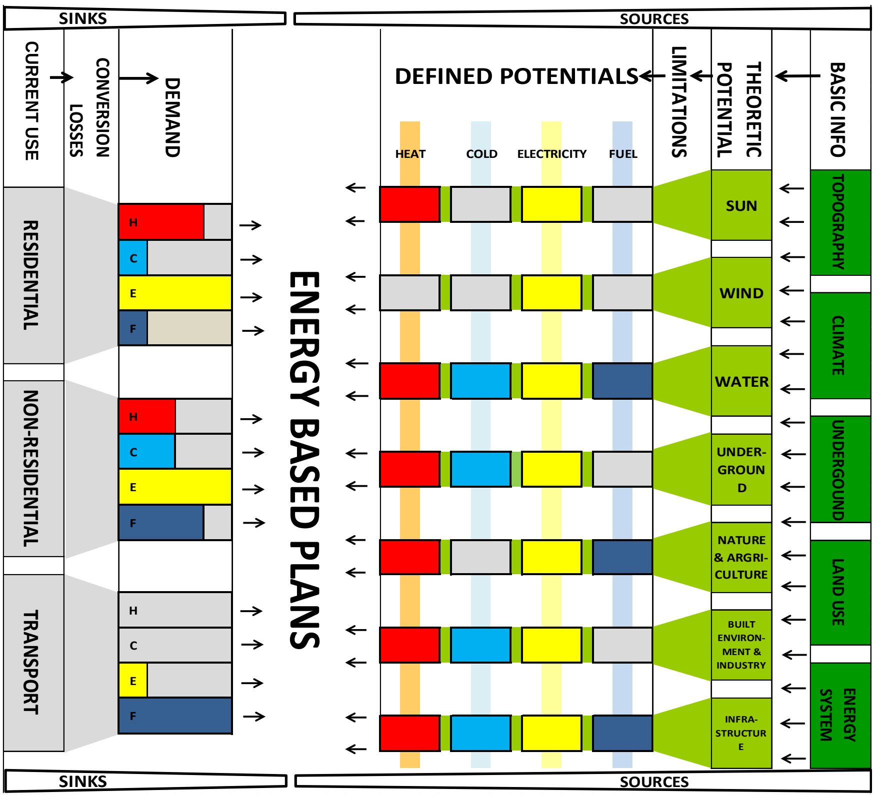

Figure 2 *Graphical explanation of the Energy Potential Mapping method, with consumers at left and potentials at right (Broersma et al., 2013)*

EPM takes into consideration conversion losses and various limitations on the demand side and theoretical renewable supply potentials in order to arrive at a more realistic potential for a chosen area, preferably while promoting multiple land use. An example would be the technical potential of photovoltaic panels on existing roofs, where the amount of solar radiation arriving at a given area is reduced by suitable roof area and orientation and expected long term PV panel performance. This can further be enhanced by structural suitability, glare issues, financial models and other local limitations and results in a detailed but realistic quantitative potential for photovoltaic electricity. Common themes on the demand side are assessing actual demand (thermal comfort, tap water heating, lighting and electricity use of appliances) from known metered figures and reduction potentials.

When combined, these form a stack of maps of many different demand and supply potential categories that provide both detailed quantified insight in and a policy-maker friendly overview of the available potentials, making it possible to arrive at a robust and realistic Energy Master Plan.

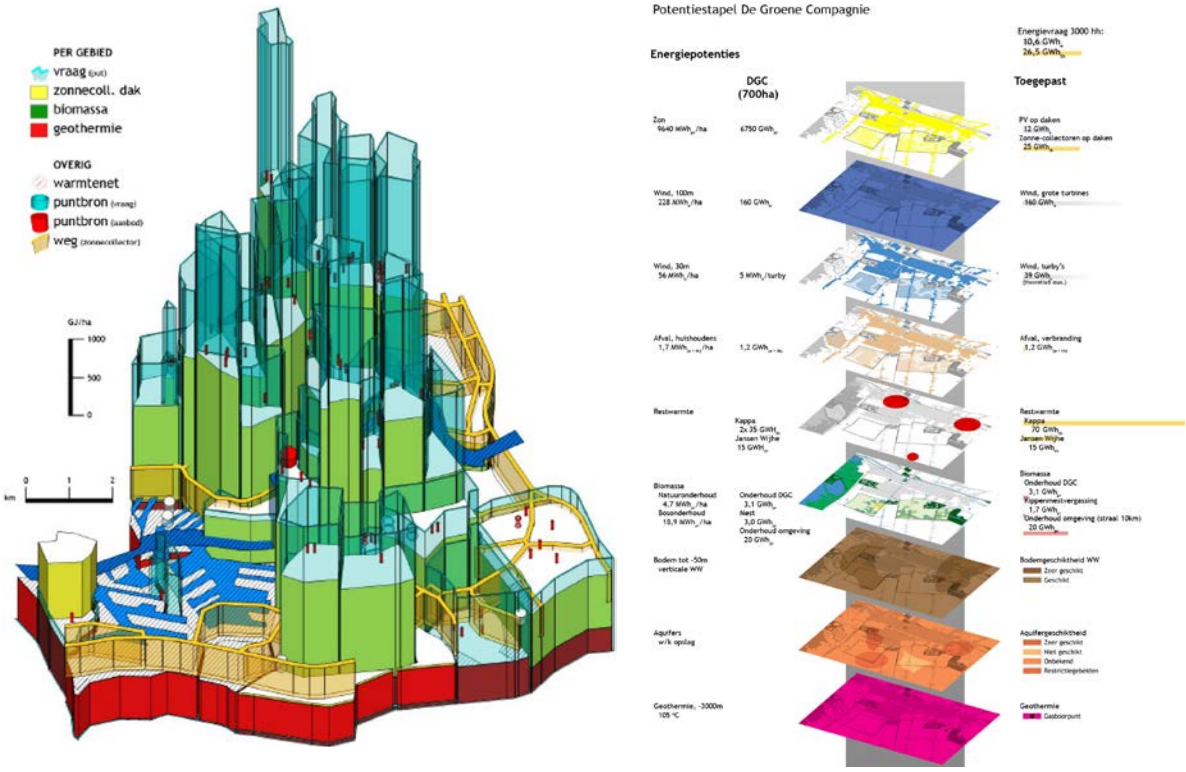

Figure 3 *(Left) Detailed 3D heat map of the central district of the city of Rotterdam: hollow cores indicate heat demands, full cores and layers are heat potentials, natural and anthropogenic (Broersma et al., 2011). (Right) Combined energy potential map stack for a neighbourhood in the Dutch town of Hoogezand-Sappemeer (Broersma et al., 2010).*

4. PRACTICAL APPLICATION IN CITY REGIONS

Rotterdam region

In the Netherlands, data are available for some 30 different housing typologies, for which average energy consumption and measures to improve energy efficiency are known. A step by step energy approach to integrate energy into spatial planning and making energy data easy accessible by EPM has proven to be a crucial part in preparing a stakeholder-based Energy Master Plan in the city.

A first step in building an Energy Master Plan was mapping the existing energy demand and reduction potentials per housing typology, which prioritised actions for policy-makers. Consequently, EPM en Heat Mapping presented the potential use of waste flows and the capacity for renewable energy generation of Rotterdam in a user-friendly format for a wide range of stakeholders as all maps were compatible to Geographical Information Systems (GIS). This meant that urban energy planning could finally be performed. Two cases will show the effect of EPM in GIS in the city. Since 2013 the Energy Atlas of Rotterdam is online. Using a 50 cm by 50 cm pixel grid, solar potentials are presented for the whole city of Rotterdam. This means that each square of 50 by 50 cm is presented with data of the feasibility of installing PV panels. The open data set is used by 2000 citizens and companies every month. Solar data are not only linked to weather data, roof angles, shading, cloud coverage etc. to get potentials as realistic as possible, but also to ownership of buildings. This way the Energy Master Plan can be translated directly into action plans. A second case is rolling out the district heating network in the city. Combining energy demand maps, heat maps, density maps and maps of existing pipelines made it possible to work with housing associations, energy companies and investors to work on a district heating master plan for the city. With threshold values agreed on by stakeholders a future district heating map could be drawn with new areas to connect, or areas to intensify, or areas where district heating was not feasible. This was a clear map for policy-makers, now translated into action plans for each area.

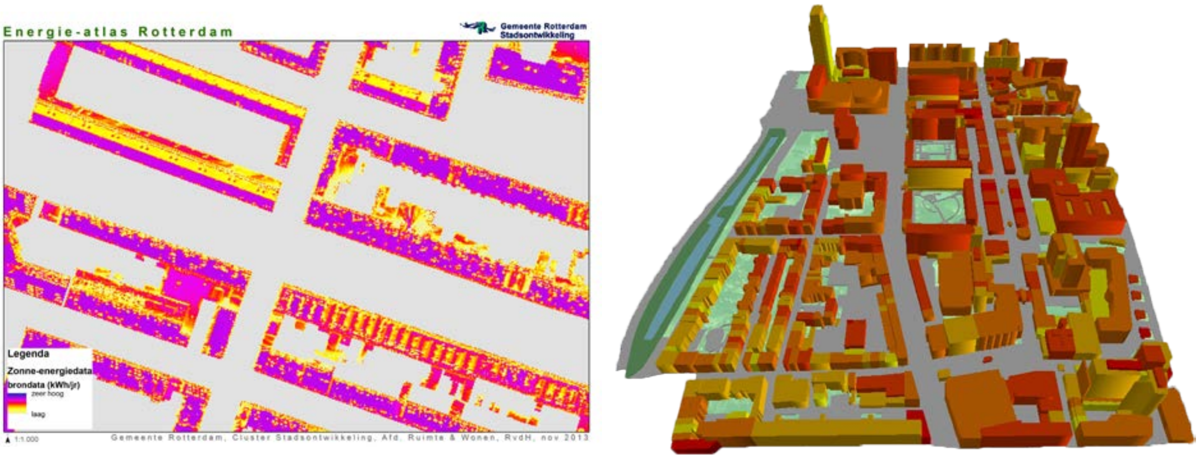

Figure 4 *(Left) 2D solar potential map in GIS of the Lijnbaan neighbourhood in Rotterdam, which can be combined with an ownership map as an example; yellow is low potential. (Right) 3D solar potential map for the same neighbourhood. Roof angles, orientation and shading are integrated in these maps; red is high potential (maps by Roland van der Heijden).*

One more important aspect of EPM is that it constituted the input for energy scenario planning methods such as GRIP, the Greenhouse Regional Inventory Protocol (Carney et al, 2009). A stakeholder-based energy scenario was the basis of the Energy Master Plan.

The energy scenario process can be run using bottom-up or top-down data. However, the internal consistency of the developed scenario pathways and their value for stakeholders will be much higher using local data as they can be directly translated into the Energy Master Plan and local actions. In short, one can state that EPM is an enabler of urban energy planning.

Oostland region

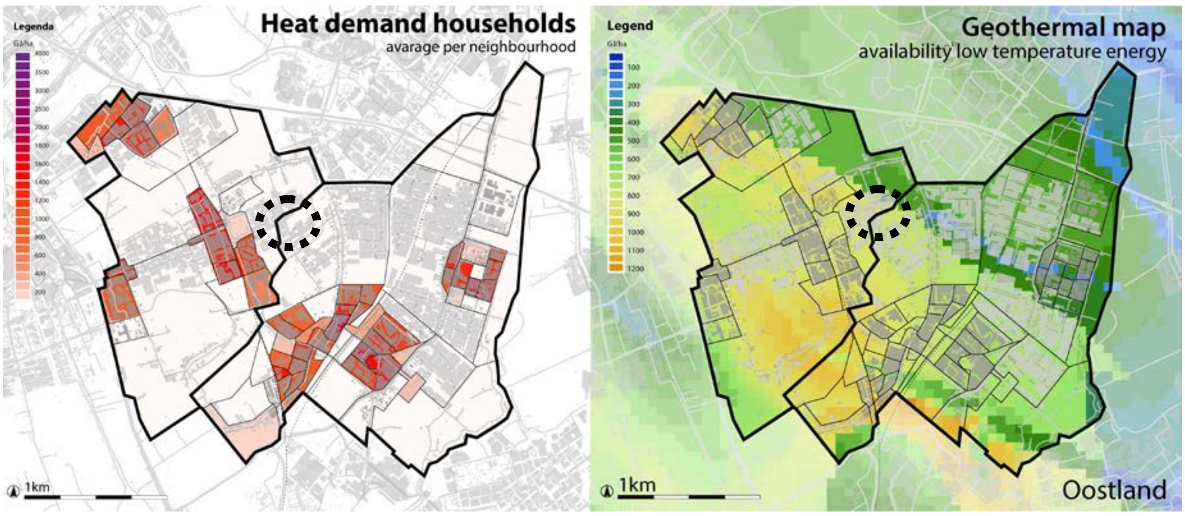

Figure 5: *Energy potential maps of heat demand of households in Oostland (left) and potentials of deep geothermal wells (right) (Broersma et al., 2013b)*

A recent regional energy study, in which the method of EPM was applied, was executed for the Dutch Oostland region (Broersma et al., 2013b). This 100 km^2 area is dominated by horticulture, spread between several smaller towns, including Pijnacker. The energy demand maps of different functions and origins as well as the various maps of sustainable potentials of the region (e.g. wind, solar, biomass, geothermal heat, thermal and electric potentials on roofs) served as the basis to expose and quantify sustainable interventions in the built environment. Figure 5 shows two examples of energy potential maps of Oostland, one of demand (left: heat demand of households) and one of supply (deep geothermal heat).

These two maps are shown here in order to explain an example of the application of EPM to a proposal of a geothermal energy cascade in the town centre of Pijnacker. The proposal is schematically shown in figure 6. The concept of a geothermal energy cascade comprises the maximised use of a geothermal energy source. This can be achieved by re-injecting the extracted hot water with the lowest possible temperature into the injection well. Different functions within the built environment can have different temperature trajectories used for heating (differences in inlet and outlet temperatures of the heating systems). If different areas, neighbourhoods or functions with consecutive temperature trajectories will be connected in series, a thermal cascade is created. Heat networks will distribute the hot water. The different districts need to have a similar heat demand too.

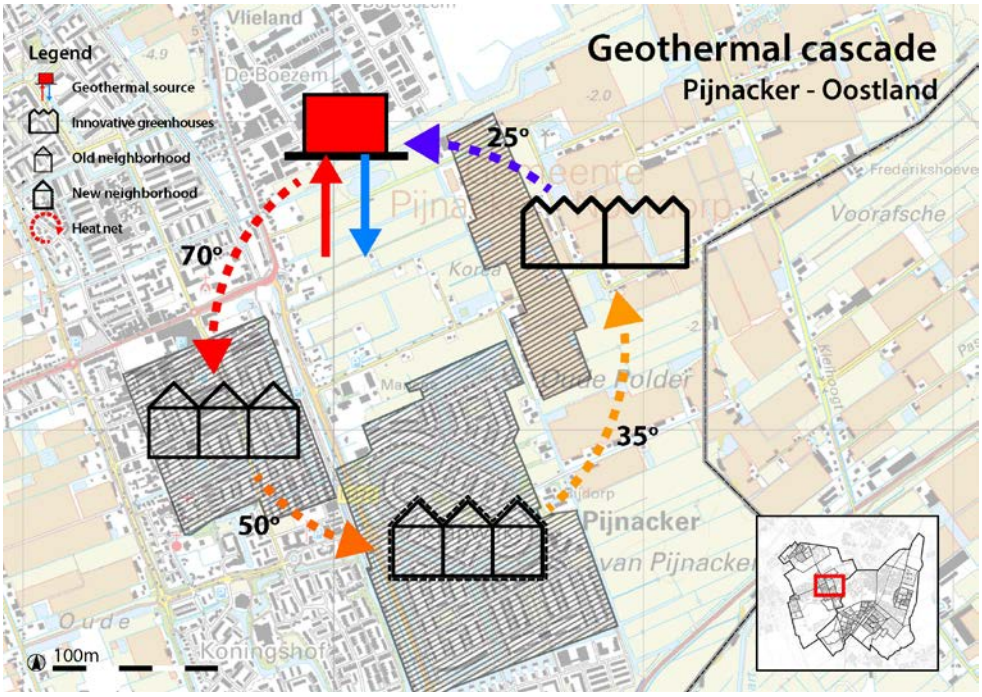

Figure 6: *Proposal of a geothermal cascade that consecutively supplies an older and newer residential area and a well-performing greenhouse area; this is based on and quantified by the energy potential maps of figure 2 (Broersma et al., 2013b).*

The centre of Pijnacker (encircled in the potential maps) has great geothermal potential. An old quarter here has a relatively high-temperature demand (~70°C inlet temperature); a significantly lower temperature could provide the adjacent newer area (~50°C inlet temperature). Adjacent to these two residential areas, a new greenhouse area is planned. If energy-efficient greenhouses are realised, very low temperatures (~35°C) will suffice. The two dashed residential areas in figure 6 have a similar heat demand. The new greenhouse area is finally dimensioned appropriately and connected by the heat supply of the cascade.

In this proposal, the present geothermal heat, at around 2000 m depth, provides a temperature of around 70°C and is re-injected at around 25°C. In the longer run, in an ideal situation, the geothermal well would be replenished by high-temperature heat in summertime, at present perhaps coming from fossil-fueled power plants, and in the future preferably from residual solar heat, won in collectors on roofs and in urban surfaces.

5. CONCLUSION

This paper discussed an approach to energetically resilient city regions, based on various energy studies that gradually led to the stepped approach, coined as the Energy Master Plan. The examples used in this paper were from the Netherlands, but the authors think the generic approach may be applied in various countries and climates, only leading to different outcomes than the relatively cool temperate climate of the Netherlands. Since this paper argued the importance of becoming energetically resilient in detail, cities anywhere across the world may profit from a generic approach that helps them to become more self-sufficient whilst maintaining the quality of life, or even increase it, when speaking of emerging or rapidly growing metropolitan areas.

The first self-sufficient city still needs to be developed, or rather: redeveloped. Many cities across the world have made vows to become climate-neutral, carbon-neutral or energy-neutral by a certain year in the nearby future, but only few of them have their energy administration up-to-date. The authors think that using the science-based approach of the Energy Master Plan, including the method of Energy Potential Mapping, will help to realise their ambitions better than using a less-rationalised approach.

By testing the approach in its full potential, flaws or specified deviations will inevitably emerge, but it is the only way to get ahead in times when old solutions do not provide an answer anymore to new challenges.

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A Comparative Analysis of Household Energy Consumption in Jakarta and Bandung

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ABSTRACT

This paper aims to reveal the detailed household operational energy consumption patterns in major cities of Indonesia. A total of 297 households were surveyed in Jakarta, while 247 households were investigated in Bandung, focusing especially on unplanned landed houses. The detailed information about household appliances and gas consumption were investigated through face-to-face interviews. The households in the two cities were grouped into three clusters based on their 'wealth' and 'household size'. It was seen that the average household energy consumption and their CO_2 emissions increase with the increase in the above two factors, in particular the 'wealth'. The household energy consumption in major Indonesian cities was predicted to increase very sharply in line with the rise of middle class in the near future if proper energy-saving strategies are not implemented. We recommended the following potential energy-saving strategies for urban houses in Indonesia: (a) provision of more apartments rather than landed houses (from the viewpoint of energy), (b) natural lighting and use of LED lamps, (c) passive cooling techniques wherever possible, and (d) insulation for building envelope.

INTRODUCTION

Indonesia has been experiencing high economic growth in line with rapid urbanization and therefore sees large increase in urban energy consumption. The real GDP increased stably by approximately 6-7% over the last few decades, whereas the nationwide final energy demand rose by 14 times from 1970s to the present (Dewi et al., 2010). Energy-saving strategies are, therefore, essential to be introduced further to make the cities more sustainable. At present, Indonesia has a population of 240 million and the percentage of people living in urban areas reached approximately 50% as of 2010. It has been reported that approximately 60% of the total population are distributed in the relatively small island, Java, which accounts for only 6% of the total national land. As a consequence, major cities in the Java Island are densely populated, such as Jakarta, Bandung and Surabaya, etc.

In Indonesia, the household sector contributes to the nationwide final energy consumption by approximately 29% in 2011 (Indonesia, 2011) and the household energy consumption is expected to increase dramatically as the middle class in urban areas rises in the near future (JETRO, 2011). At present, most of the residential buildings in major cities are considered to be unplanned houses called '*Kampungs*'. These dwellings were settled in unplanned and overcrowded urban villages without being provided properly with basic urban infrastructure and services. These unplanned houses account for a large proportion in the existing housing stocks in the major cities: 74% in Jakarta, 89% in Bandung and 98% in Surabaya, etc.

The objective of this study is to reveal the detailed household operational energy consumption patterns in major cities of Indonesia. A total of 297 households were surveyed in Jakarta, while 247 households were investigated in Bandung, focusing especially on unplanned landed houses. Firstly, the samples of the two cities are classified into several groups based on household characteristics through a cluster analysis in order to analyze their household energy consumption patterns. Secondly, multiple regression analyses are carried out for respective cities to figure out the causal structures on the household energy consumption. Potential energy-saving strategies for urban houses in Indonesia are discussed based on the results of the above analyses.

METHODS

Jakarta, the capital city, has a population of 9.6 million in 2010 while that of Bandung is 3.3 million as of 2011. Both of the cities saw rapid population growth over the last few decades. The two cities are situated in the West Java and experience uniform hot-humid climates throughout the year. However, the average temperature in Bandung is not as high as other cities because of its relatively high altitude (700-800 m above the sea level). The monthly average temperature ranges from 22.9-23.9°C in Bandung, whereas that of Jakarta is 27.1-28.9°C. Due to the relatively cool climate, few houses use air-conditioning in Bandung.

As described before, the majority of urban houses are considered unplanned houses in Indonesia. The Indonesian government further classifies these unplanned houses into three categories based on construction cost and lot area, namely simple, medium and luxurious houses (Figure 1). Although the quality and size of houses differ among these three house categories, they are similarly constructed of brick-walled structure. Moreover, most of the building materials used and the construction methods of these houses are similar regardless of the house category (Surahman and Kubota, 2013).

A total of 14 typical residential neighborhoods were selected in Jakarta while six areas were chosen in Bandung for the surveys. The survey was conducted in Jakarta from September to November 2012, whereas it was carried out from September to October 2011 in Bandung. A total of 297 and 247 houses were investigated respectively (see Table 1). The detailed information about household appliances and gas consumption were obtained by means of face-to-face interviews using a questionnaire form. The content of the questionnaire covers the following items: (a) socio-economic profile, (b) building information, (c) monthly energy bills (electricity, water, gas (LPG), and kerosene), and (d) number and usage time of household appliances. Meanwhile, on-site measurements using watt meters (MWC01, OSAKI) were carried out to investigate the electric capacity of respective household appliances. Then, the monthly average household electricity consumption was estimated based on the data of (a) number of appliances, (b) usage time, and (c) measured electric capacities. These measured electricity consumption was validated by the data obtained through the electricity bills. The monthly gas (LPG) and kerosene consumption was estimated simply based on the data from their bills.

The annual average household energy consumption was then calculated in the form of secondary energy by combining electricity consumption for all the household appliances as well as gas and kerosene consumption. As explained before, the seasonal variation in climate conditions is not large in both Jakarta and Bandung. Therefore, the usage time of appliances was assumed to be constant

Figure 1 *Views of sample houses. (a) Simple house; (b) Medium house; (c) Luxurious house.*

throughout the year. Nevertheless, the small seasonal changes of air temperature and humidity were considered in the estimation of energy consumption caused by air-conditioners and refrigerators, though the resulting changes were found to be negligible.

The primary energy used for generating electricity in Indonesia comprised 42% of coal, 17% of oil, 28% of natural gas, 10% of hydro and 3% of geothermal as of 2010 (Indonesia, 2010; IEA, 2012a). Finally, the electricity consumption was converted into primary energy by considering the above energy mix, electric efficiencies and transmission losses in order to estimate the household CO_2 emissions.

Table 1. Socio-economic profile of respondents

	Jakarta	Bandung
Sample size	297	247
House category (%)		
Simple	42.1	48.6
Medium	38.7	40.1
Luxurious	19.2	11.3
Gender (%)		
Male	50.5	39.3
Female	49.5	60.7
Age (%)		
< 40 (years old)	21.9	17.0
40-49	33.7	27.9
50-60	32.3	32.0
> 60	12.1	23.1
Household size (persons)	4.5	4.8
Monthly household income (%)		
< 90 (US$)	3.0	4.5
90-450	58.9	61.5
450-900	26.6	28.7
> 900	11.5	5.3
Total floor area (%)		
< 50 (m^2)	33.7	25.9
50-99	28.3	32.4
100-300	34.0	37.7
> 300	4.0	4.0

RESULTS AND DISCUSSION

Profile of respondents

Table 1 shows the socio-economic profile of the respondents. The percentages of simple, medium and luxurious houses are approximately 42%, 38% and 20% in Jakarta, and 48%, 40% and 12% in Bandung. These percentages were determined to represent the approximate proportions among all houses of the cities, respectively. As shown in Table 1, the average household size of the respondents was approximately 4.5-5.0 persons in both of the cities. The luxurious houses tend to have slightly larger households of about 5.5 persons. The proportions of household income strata are almost the same between the two cities, although the average income in Jakarta is slightly higher than that of Bandung. In general, household income increases with the house category from simple to luxurious houses.

Classification of households: Factor analysis and cluster analysis

In order to figure out the socio-economic and demographic characteristics that affect their household energy consumption patterns, an exploratory factor analysis with principal axis factoring and a cluster analysis were carried out for the combined whole samples of the two cities (n=544). The orthogonal varimax rotation was employed and the factors were determined based on the eigenvalues (>1). As shown in Table 2, three factors were extracted from the combined samples. The variables with rotated factor loads of more than 0.4 were grouped into the same groups. These three factors were named as follows: 'Factor 1: Wealth', 'Factor 2: Building age', and 'Factor 3: Household size'.

It was found that both Factors 1 (wealth) and 3 (household size) have significant relationships with household energy consumption respectively. Then, cluster analyses were conducted by using factor scores of the selected two factors (i.e. 'wealth' and 'household size') for the combined samples (Figure 2). Since sample sizes were relatively large, the *K*-means nonhierarchical clustering technique was adopted. By considering the resulting average household energy consumption values, three clusters were determined for the combined samples (Figure 2). In both cities, the factor score of Factor 1 (wealth) consisting of total floor area, house category, household income, lot area, and educational attainment, increases from Cluster 1 to 3. However, the wealth levels are almost the same between Cluster 1 and 2 in both cities. Instead, the households in Cluster 2 have larger household size than those of Cluster 1 as shown in Figure 2.

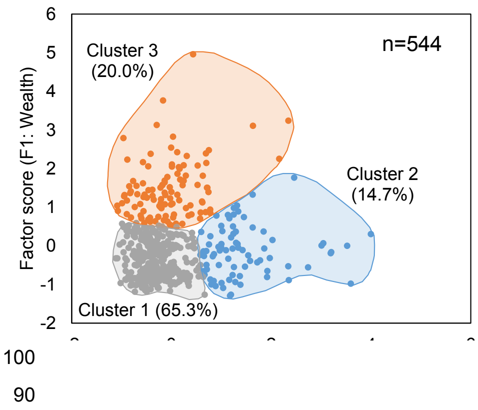
Household energy consumption by clusters

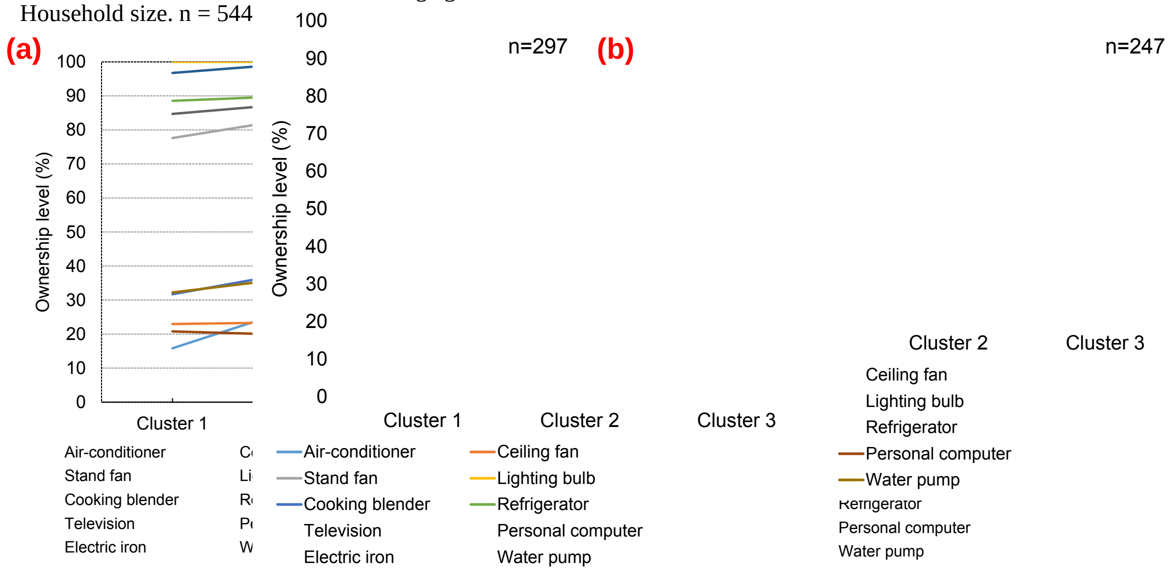
Figure 3 presents the ownership levels of major household electric appliances in respective case

Table 2. Rotated factor matrix (Jakarta and Bandung)

Variable	Factor 1	Factor 2	Factor 3
Total floor area	0.822	0.003	0.079
House category	0.820	-0.093	0.074
Household income	0.673	-0.081	0.262
Lot area	0.659	0.004	-0.024
Educational attainment	0.582	-0.061	-0.057
No. of building story	0.338	0.065	0.150
Building age	-0.060	0.928	0.034
Living duration	-0.021	0.910	0.099
Household size	0.182	0.090	0.658
No. of household	-0.013	0.019	0.607
% of variance	27.24	17.22	9.18

Note: Factor 1, Wealth; Factor 2, Building age; Factor 3, Household size. n = 544





studies. As shown, lighting bulb (100%), television (95-100%) and refrigerator (79-100%) recorded high ownership levels similarly in the two cities among three clusters. In the case of Jakarta (Figure 3a), the stand fan also recorded high ownership levels of 78-84%, reflecting its severe hot climatic conditions. In general, the ownership levels of other appliances increase from Cluster 1 to 3 respectively, except for a few appliances such as water pump in Bandung. The ownership levels of air-conditioners significantly differ between the two cities: they are 16-79% in Jakarta and 0-17% in Bandung.

In both cities, compact fluorescent lamps are well penetrated among households regardless of the clusters (Figure 4). It has been reported that the Indonesian government highly promoted fluorescent lamps for replacing incandescent lamps from 2007 (BUMN, 2007). The national power company (i.e. *Perusahaan Listrik Negara*) exchanged one incandescent bulb by three compact fluorescent bulbs for free for their customers all over Indonesia with the aim of reducing the nationwide electricity consumption and the government's subsidies for electricity tariffs.

Figures 5 and 6 show the annual household energy consumption (secondary energy) averaged in respective clusters. Figures 5a and 6a indicate the energy consumption by different energy sources and Figures 5b and 6b show those by different end-use categories. Overall, the average annual energy consumption in Jakarta is approximately 5,726 kWh, which is 1,402 kWh larger than that of Bandung. The difference is mainly attributed to the use of air-conditioning between the two cities. As shown in Figure 5b, the energy consumption for cooling accounts for 22% in Jakarta on average, whereas the corresponding percentage is only 1.3% in Bandung. Hence, in the case of Jakarta, basically, the average household energy consumption of clusters increases with the increase in ownership and use of air-conditioning (Figures 3a and 5b). In the case of Bandung, the energy consumption for cooking, lighting, entertainment and power, etc. largely influence the increase in the overall energy consumption (Figure 5b). As described before, Clusters 1 and 2 have similar wealth levels on average, while Cluster 2 has larger household size than Cluster 1 in both of the cities (see Figure 2). As shown in Figure 5b, the

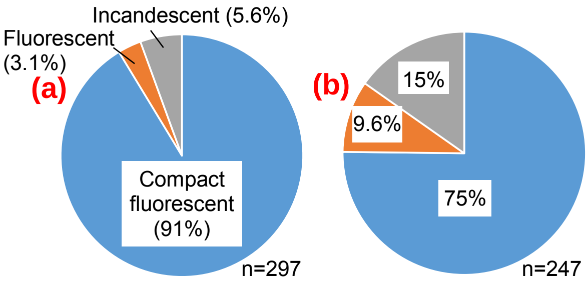
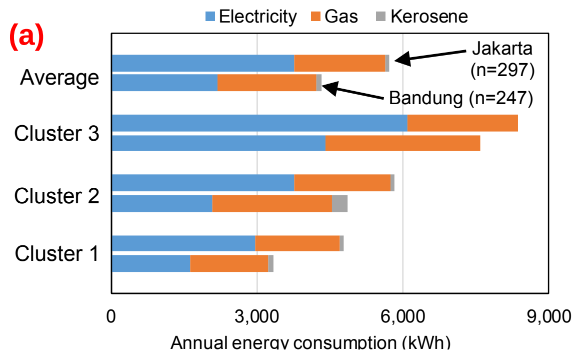


Figure 4 *Percentage of lighting bulbs used in their houses. (a) Jakarta; (b) Bandung.*

Table 3. CO_2 emission factors

Energy source	CO_2 emission factor (kg CO_2-eq/GJ)	Source
Electricity	196.9	IEA, 2012b
LPG	66.7	Kurdi, 2006
Kerosene	72.5	Kurdi, 2006



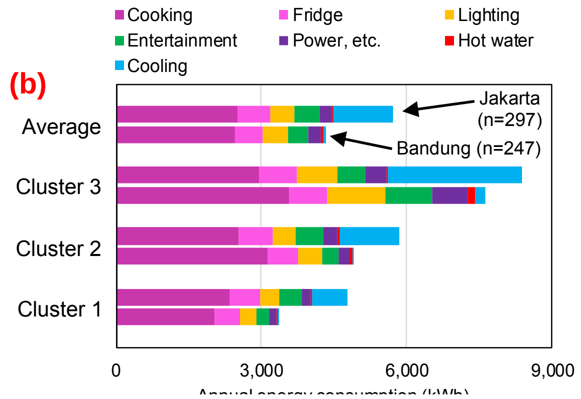


Figure 5 *Annual household energy consumption by clusters (Secondary energy). (a) by energy source; (b) by end-use.*

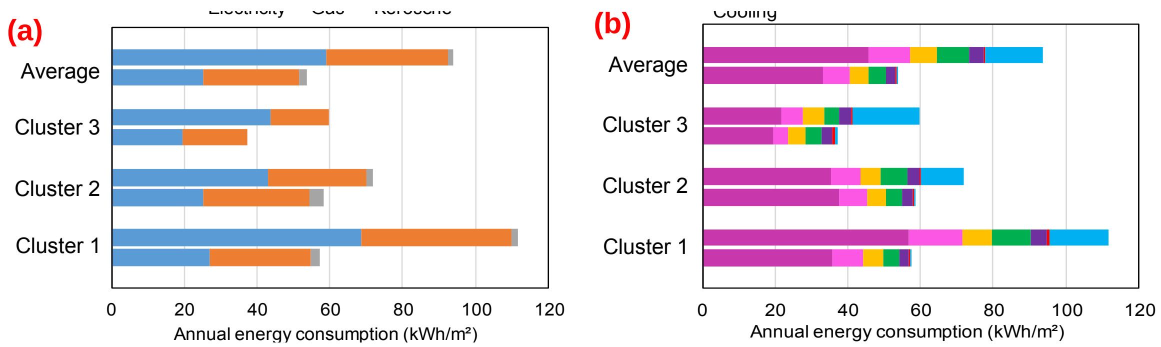


Figure 6 *Annual household energy consumption per square meter by clusters (Secondary energy). (a) by energy source; (b) by end-use.*

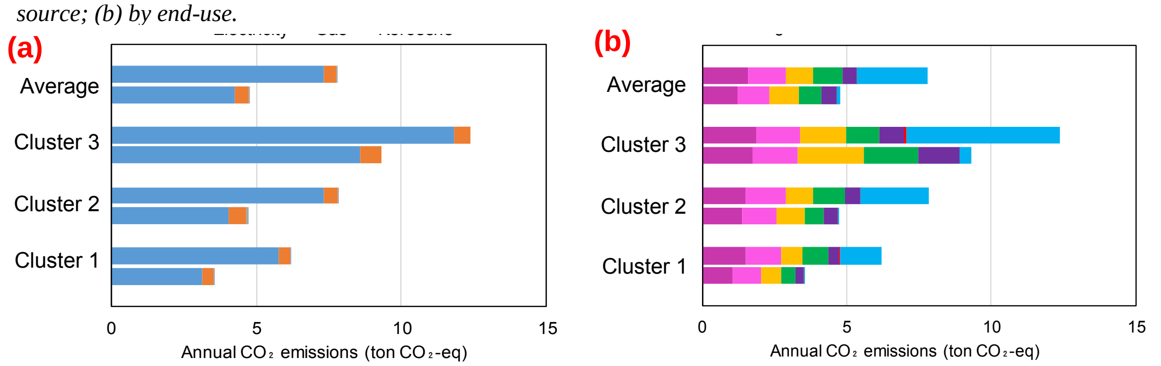


Figure 7 *Annual household CO_2 emissions by clusters (Primary energy). (a) by energy source; (b) by end-use.*

difference of household size between Cluster 1 and 2 cause a significant difference in energy consumption for cooking in the case of Bandung. In both of the cities, electricity consumption is larger than that of LPG and kerosene except for Clusters 1 and 2 of Bandung, even when they are assessed based on secondary energy: 62-73% in Jakarta and 43-58% in Bandung (Figure 5a).

Figure 6 shows the corresponding annual energy consumption per square meter. Interestingly, the averaged energy consumption decreases from Cluster 1 to 3, except for Clusters 1 and 2 of Bandung. This is mainly because the occupant density declines from Cluster 1 to 3 accordingly. In particular, the average total floor area of houses in Cluster 1 of Jakarta is so small (64 m^2) that the corresponding energy consumption per square meter is larger than the others.

The annual household CO_2 emissions were estimated through multiplying the energy consumption

Table 4. Results of multiple regression analyses, depicting causal structure on household energy consumption. (a) Monthly electricity consumption; (b) Monthly gas (LPG) consumption; (c) Household appliances. (*=5% significance; **=1% significance)

(a)

Jakarta

Variable	β		r	
Air-conditioner	0.71	**	0.84	**
Television	0.21	**	0.37	**
Stand fan	0.20	**	0.21	**
Ceiling fan	0.16	**	0.09	
Refrigerator	0.14	**	0.34	**
Lighting bulb	0.12	**	0.69	**
Rice cooker	0.11	**	0.13	*
Washing machine	0.11	**	0.34	**
Water pump	0.10	**	0.22	**
R^2	0.93	**		
n	297			

Bandung

Variable	β		r	
Water pump	0.35	**	0.53	**
Television	0.29	**	0.62	**
Lighting bulb	0.26	**	0.66	**
Refrigerator	0.24	**	0.53	**
Personal computer	0.17	**	0.39	**
Washing machine	0.14	**	0.50	**
Stand fan	0.12	**	0.32	**
Electric iron	0.11	**	0.30	**
R^2	0.87	**		
n	247			

(b)

Jakarta

Variable	β		r	
Household size	0.23	**	0.25	**
Lot area	0.14	*	0.17	**
R^2	0.08	**		
n	297			

Bandung

Variable	β		r	
Household size	0.32	**	0.33	**
Lot area	0.14	*	0.15	**
R^2	0.13	**		
n	247			

(c)

Jakarta

Air-conditioner

Variable	β		r	
Total floor area	0.52	**	0.62	**
Household income	0.31	**	0.49	**
Age of husband	-0.09	*	0.03	
R^2	0.47	**		
n	297			

Television

Variable	β		r	
Total floor area	0.16	**	-	
R^2	0.02	**		
n	297			

Stand fan

Variable	β		r	
No. of children	0.13	*	-	
R^2	0.02	*		
n	297			

Bandung

Water pump

Variable	β		r	
Household income	0.43	**	-	
R^2	0.18	**		
n	247			

Television

Variable	β		r	
Lot area	0.36	**	0.56	**
Household income	0.34	**	0.55	
R^2	0.39	**		
n	247			

Lighting bulb

Variable	β		r	
Total floor area	0.70	**	-	
R^2	0.49	**		
n	247			

(primary energy) for each fuel type by its corresponding CO_2 emission factor (Nansai et al., 2002; Surahman and Kubota, 2013). Table 3 presents the CO_2 emission factors used for this analysis. As indicated in Figure 7, the average annual CO_2 emission in Jakarta is estimated at 7.8 ton CO_2-equivalent, while that of Bandung is 4.8 ton CO_2-equivalent. The major contributors in Jakarta are cooling (2.4 ton (31%)), cooking (1.6 ton (20%)) and refrigerator (1.3 ton (17%)), while those in Bandung are cooking (1.2 ton (26%)), refrigerator (1.1 ton (23%)) and lighting (1.0 ton (21%)). If the amount of CO_2 emissions caused by cooling are excluded, then the difference of total CO_2 emissions between the two cities would be insignificant (5.4 ton in Jakarta and 4.7 ton in Bandung). This clearly indicates that the increase in use of air-conditioning in the future would dramatically increase the household energy consumption and therefore their CO_2 emissions.

Causal structures on household energy consumption: Multiple regression analyses

Multiple regression analyses were carried out to further analyze the causal structure on household energy consumption in the two cities (Table 4). Since electricity and LPG were found to account for almost all the energy consumption in the two cities (see Figure 5a), firstly, we examined the major factors explaining consumption of these two energy sources (Table 4ab). In this analysis, the new variables (electricity consumption caused by respective appliances) were created for each of the household electric appliances by multiplying its electric capacity by the number of the appliance and its usage time. Secondly, further determinants for respective electric appliances were analyzed in the two cities respectively (Table 4c).

As shown in Table 4a, the major appliances contributing the electricity consumption largely differ between the two cities. In the case of Jakarta, air-conditioner (β=0.71) is found to be the major determinant for the electricity consumption in this model, followed by television (0.21), stand fan (0.20), ceiling fan (0.16), and refrigerator (0.14), etc. As seen in Figures 5b, 6b and 7b, this result confirms that energy consumption for cooling appliances, in particular air-conditioners, is significant and large in the case of hot-humid climate of Jakarta. In contrast, in the case of Bandung, water pump (β=0.35) is found to be the most influential contributor for the electricity consumption in this model, followed by television (0.29), lighting bulb (0.26), and refrigerator (0.24), etc. Both of the regression models obtain high R^2-values of 0.93 and 0.87, respectively. The determinants for LPG consumption are similar in the two models for respective cities, although both of the R^2-values record low values of 0.08 and 0.13 respectively (Table 4b). In the two cities, both household size and building size may be able to explain weakly the LPG consumption.

As shown in Table 4c, in Jakarta, the energy consumption caused by air-conditioning, which is the main contributor to the electricity consumption, can be explained by the total floor area, the household income and the age of husband with a coefficient of determinant of 0.47. Other major appliances (i.e. television and stand fan) are weakly explained by the total floor area and the number of children, respectively. On the other hand, in Bandung, water pump is weakly explained by the household income. Other major appliances (i.e. television and lighting bulb) can be determined by the lot area and the household income, and total floor area, respectively.

It is seen that overall, the increase in household income and building size, such as total floor area and lot area, increase the electricity consumption caused by the major appliances. In both of the cities, it was found that the increase in household income increase their building size such as the total floor area (r = 0.38** in Jakarta and r = 0.72** in Bandung) and the lot area (r = 0.39** in Jakarta and r = 0.60** in Bandung). Hence, it is anticipated that the further increase in household income would increase the building size, thus the energy consumption caused by major household appliances. As a consequence, the increase in household income would increase the total household energy consumption significantly in the near future in Indonesian cities. It has been reported that the household income in Indonesia is predicted to rise dramatically in the near future in line with the rise of middle class as described before (JETRO, 2011). The household energy consumption in major Indonesian cities is predicted to increase very sharply if proper energy-saving strategies are not implemented.

It is important to avoid the tendency that building size increases straightforwardly with the increase in household income. From the viewpoint of energy, one of the possible solutions is to recommend more apartments rather than landed houses that generally increase total floor area. It should be noted that most of the incandescent bulbs were already replaced by compact fluorescent bulbs in Indonesian cities. This means that further energy-saving should be made for lighting by utilizing more natural lighting or using LED lamps. The increase in air-conditioning would be a major concern in terms of the energy-saving strategies in Indonesia (the relatively cool climate of Bandung is not typical of other major cities). Even in Jakarta, the ownership level of air-conditioner was only 32% on average at the moment in this survey. It is important to reduce the use of air-conditioning in the future despite the expected increase in household income. Passive cooling techniques should be adopted wherever possible. Insulation for building envelope should also be considered.

On the other hand, the current energy efficiency in electricity generation in Indonesia is not as good as other developed nations. The total loss due to electric efficiency and transmission losses results in the increase in primary energy consumption by approximately 2.7 times than the end-use electricity consumption. This exceeds the scope of this paper but this should also be considered in the future energy-saving strategies in Indonesia.

CONCLUSIONS

Key findings are summarized as follows:

1. The households in Jakarta and Bandung can be grouped into three clusters based on their ‘wealth’ and ‘household size’. It was seen that the average household energy consumption and CO_2 emissions increase with the increase in the above two factors, in particular the ‘wealth’. Overall, the average annual energy consumption in Jakarta was approximately 5,726 kWh, which was 1,402 kWh larger than that of Bandung. Accordingly, the average annual CO_2 emission in Jakarta was estimated at 7.8 ton CO_2-equivalent, while that of Bandung was 4.8 ton CO_2-equivalent.
2. The difference of household energy consumption and CO_2 emission between the two cities was mainly attributed to the use of air-conditioning. The ownership levels of air-conditioners significantly differed between the two cities: they are 16-79% in Jakarta and 0-17% in Bandung. It was predicted that the increase in use of air-conditioning in the future would dramatically increase the household energy consumption and therefore their CO_2 emissions.
3. It was anticipated that the further increase in household income would increase the building size, thus the energy consumption caused by major household appliances. As a consequence, the increase in household income would increase the total household energy consumption significantly in line with the rise of middle class in the near future in Indonesian cities if proper energy-saving strategies are not implemented.
4. It is important to avoid the tendency that building size increases straightforwardly with the increase in household income. We recommended the following potential energy-saving strategies for urban houses in Indonesia: (a) provision of more apartments rather than landed houses (from the viewpoint of energy), (b) natural lighting and use of LED lamps, (c) passive cooling techniques wherever possible, and (d) insulation for building envelope.

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Examining the Environmental and Energy Challenges of Slums in São Paulo, Brazil

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ABSTRACT

*The city of São Paulo is the richest city in Brazil, accounting for more than 12% of the national GDP, offering employment opportunities for the countries' middle class as well as for the poor (*IBGE, 2012*). As a result, approximate 2 million people live in slums with deficient urban infrastructure (*FRANÇA, COSTA, 2012*). In the last decade, the increase buying power of the low income families in the big cities of the country has caused a dramatic raise on electricity demand due to the acquisition of domestic appliances, which have proved to become comparable to those of middle class, based on the data gathering in the fieldwork research presented in this paper. Hence, the growth of urban slums in Sao Paulo is associated with the increase of its population density accompanied by an increase of electricity demand, adding pressure on the precarious infrastructure and impoverishing even more the living conditions, due to the accumulation of heat gains in compact irregular and overcrowded housing, agglomerated in informal settlements of poor quality open spaces. In this context, this work examines the environmental challenges of slums in the city of São Paulo, the so called "favelas", drawing from two cases: "favela Morro da USP", covering 18.500m² and housing 515 families, and "favela Paraisopolis", the second biggest in São Paulo, with almost 60.000 inhabitants living over 100 hectares. Field work has shown energy consumption of the slums' households of around 220kwh/month, the equivalent to the typical figures from the local middle class homes. In addition, the environmental research has identified the potencial of improving internal conditions with bigger openings to higher ventilation rates and shading of roof components.*

INTRODUCTION

Being the 10th richest city in the world, São Paulo entered the new century accounting for 12.26% of the national GDP and 36% of the total output of goods and services of the State of São Paulo (IBGE, 2012). Associated with its economic development, the city of São Paulo is seen as a place of employment opportunities, availability of infrastructure and assess to education, health, leisure and culture in the country. On the other hand, economic and urban growth has also reflected in a series of socio-economic, urban and environmental negative impacts, compromising the quality of life of various neighbourhoods in the city, formal and informal. In this context, the housing deficit is one of the most critical issues in the city. According to the census of 2010 (IBGE, 2010), 1.16 million people were counted

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in the slums, 1.8 million inhabitants in irregular settlements, and about 9,000 homeless in the city of São Paulo. The phenomena of the *favelas* in São Paulo, which started in the 70s, became visible and distinguished in the urban fabric of the city (figure 1).

Covering an area of almost 2 hectares (18.500m²) and housing 515 families, *Favela Morro da USP* is a small informal settlement where 50% of residents live in units smaller than 30m^2 (Pizarro, 2014). On the other end, *Favela Paraisopolis* is the second biggest slum in São Paulo, with almost 60.000 inhabitants living over 100 hectares (França, Costa, 2012). Whilst the first case has the population and a total area equivalent to a couple of typical urban blocks, *Paraisopolis* covers a territory of a medium size city in the country. Despite these differences, both case studies have similar social and physical structure, typical of the consolidated urban slums in the city. The consolidated slum in São Paulo has a basic infrastructure in place (roads, water, sewage and energy utilities), the permanent character of the buildings and the identification of a coherent social organization. Problems for the quality of life are found in the lack of open spaces and in the environmental conditions of the residences.

Figure 1 Overview of *Paraisopolis*, the 2nd biggest slum of Sao Paulo, in cityscape of the city. Photo: Eduardo Pizarro.

CLIMATE

The city of São Paulo is located in the latitude 23º24'south, with a tropical climate subjected to the effects of altitude (approximately 800 metres above sea level) where thermal comfort is likely to be achieved for approximately 70% of the year (ASHRAE, 2009). The climate offers sunny winter days, when direct solar radiation is a key factor for thermal comfort, especially in outdoor spaces, and partially cloudy days in summer, when the main strategy for thermal comfort is solar protection combined with natural ventilation.The mean air temperature in the summer months stays around 23^{o}C, whilst humidity can easily reach 80 per cent (figure 2). However, it is worth highlighting that in the hot periods of the year, thermal comfort indoors and outdoors is highly dependent on shading strategies and proper ventilation rates. Winters are mild, with mean air temperatures between 16^{o}C and 18^{o}C, though even in winter relative humidity stays high. Heating demand is identified for short periods of the year, being easily solved passively with solar gains and internal gains from dense ocuppantion patterns.

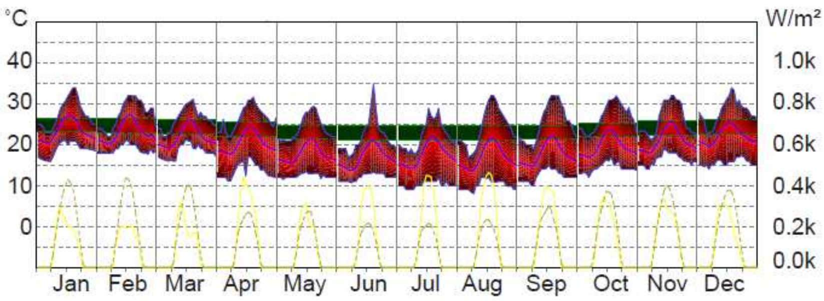


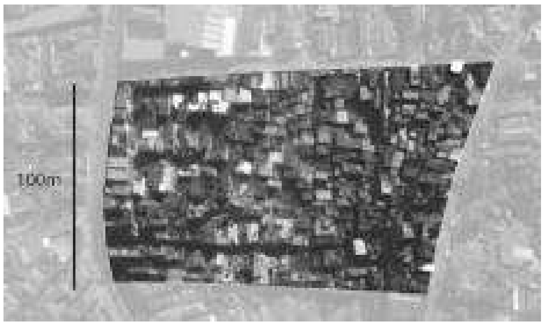
Figure 2 Monthly average temperatures of the climate of Sao Paulo with incident radiation. Source: Pizarro, 2014.

In addition to the characteristics of the natural climate, the city presents a huge variety of urban microclimates, influenced by the multiple aspects of the urban form and human activities and characterized by problems with air quality, urban heat islands, poor urban ventilation, urban noise, among others, which affect the quality of both open spaces and buildings, typical in the slums (CETESB, 1990, Silva, Ribeiro, 2006). Moreover, it is important to consider that, in the residential units, high occupation density coupled with insufficient air changes (due to small windows), compromise the internal environmental conditions in the warm days of the year, as shown bellow.

THE BUILT ENVIRONMENT OF SLUMS

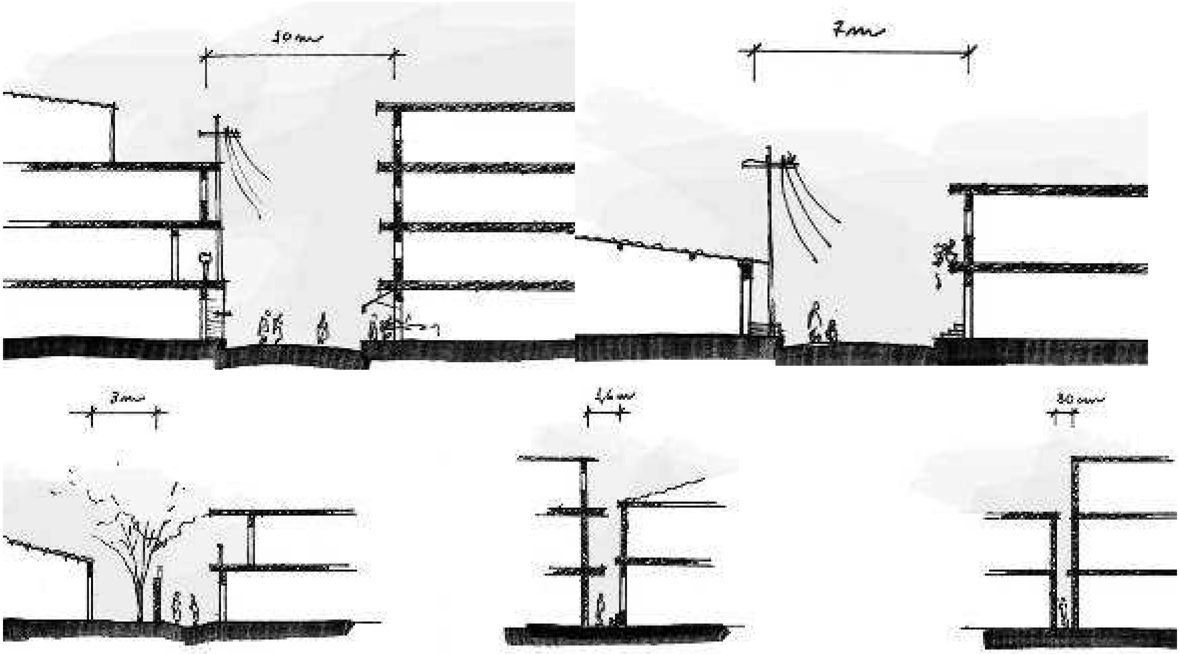
Urban fabric

Originally, the urban fabric of both case studies (as in the majority of slums in Sao Paulo) developed on top of a formal parceling of the territory (figures 3 and 4). As a consequence, main roads were kept within their original size (10 meters long), whilst a complex grid of alleys grew within the urban blocks to give access by foot to the internal and smaller residential units (figures 5 to 8). As a result, the built environment is characterized by a diveristy of circulation spaces with constrasting environmental conditions in need of improvement. The compactness of the urban blocks leads to lack of vegetation and space to the accommodation of urban and living activities, which are either castigated by solar radiation or deprived of daylight and air flow between buildings due to the rather narrow canyons (figures 5 and 6).

Figures 3 and 4 On the left, the urban fabric of *Favela Paraisopolis*, over 100 hectares. On the right, the site planning of *Favela Morro da USP*, covering the small area of 2 hectares. Despite the difference in size, both cases have a similar parttern of urban fabric. Source: Pizarro, 2014.


Figures 5 and 6 The urban environment in *Favela Paraisopolis*. On the left, the canyon and socioeconomic activities on the pavement of the main street. On the right, the appropriation of open space of the alley. Photo: Eduardo Pizarro.



Figures 7 and 8 Sections of the typical canyons in the slums of *Morro da USP* and *Paraisópolis*. Above two of the main streets shared by pedestrians and cars. Below the pedestrians´ alley. Source: Pizarro, 2014.

The building

The buildings in the slums of Sao Paulo vary from one to four storeys, supported by concrete columns and beams and brick walls. The area of the residential unit (one per floor), vary from 30 to 50m^2, for an average family size of four people. Typically, each residence has one façade to the exterior. As identified in Samora and Vosgueritchian (2006), the limited exposure to the outside combined with the compatness of the urban fabric incurs to internal spaces characterized by lack of solar access, daylight and ventilation. On the other hand, the thermal capacity of the buildings, in addition to the self shading of the urban fabric and external shading strategies, protects internal and external spaces from the harsh impact of solar radiation.


Figures 9 and 10 On the left, view of a typical street within the fabric of *Favela Morro da USP*. On the right, view of multistorey buildings supported by concrete columns and beams with brick walls.

ENVIRONMENTAL CONDITIONS AND CHALLENGES

Outdoor environment: walking through the streets of *Paraisopolis*

Measuraments of environmental variables in the streets of *Paraisopolis* included air temperatures, surface temperatures, relative humidity and air movement. Comparing the results found in the streets with those from the alleys, the fieldwork showed the significant positive impact of the shading and shaded mass in reducing surface and air temperatures in hot days. The unshaded street presented surface temperatures as high as 50^{o}C and air temperature around 36^{o}C (figure 11). In contrast to that, within a short period of time, the protected space of alley had higher air temperatures around 36 ^{o}C but significantly lower surface temperatures, showing figures around 28 ^{o}C, which have a major favourable impact on pedestrians' comfort and on the thermal conditions within the rooms facing the alleys (figure 12). Air movement also varied from higher than 2 m/s in the main street to around 1.5 m/s in the alley, in the best scenario. Nevertheless, insufficient daylighting in the alleys is obvious.

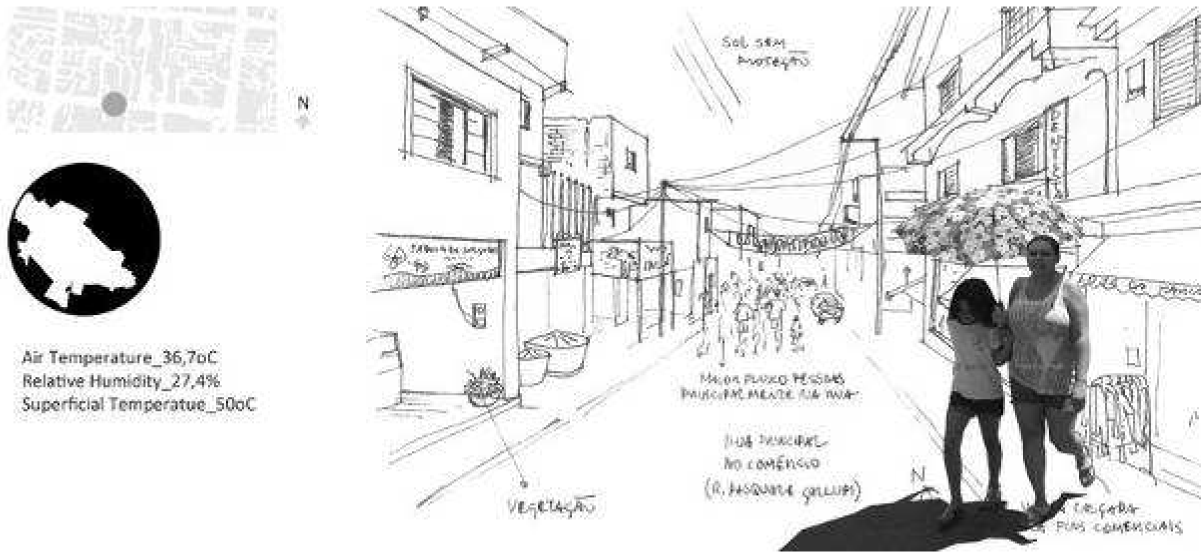


Figure 11 Sinthesis of thermal conditions in one of the main streets of *Paraisopolis,* showing air temperature, surface temperature, relative humidty and air movement taken on a hot day at 4 pm. Source: Pizarro, 2014.

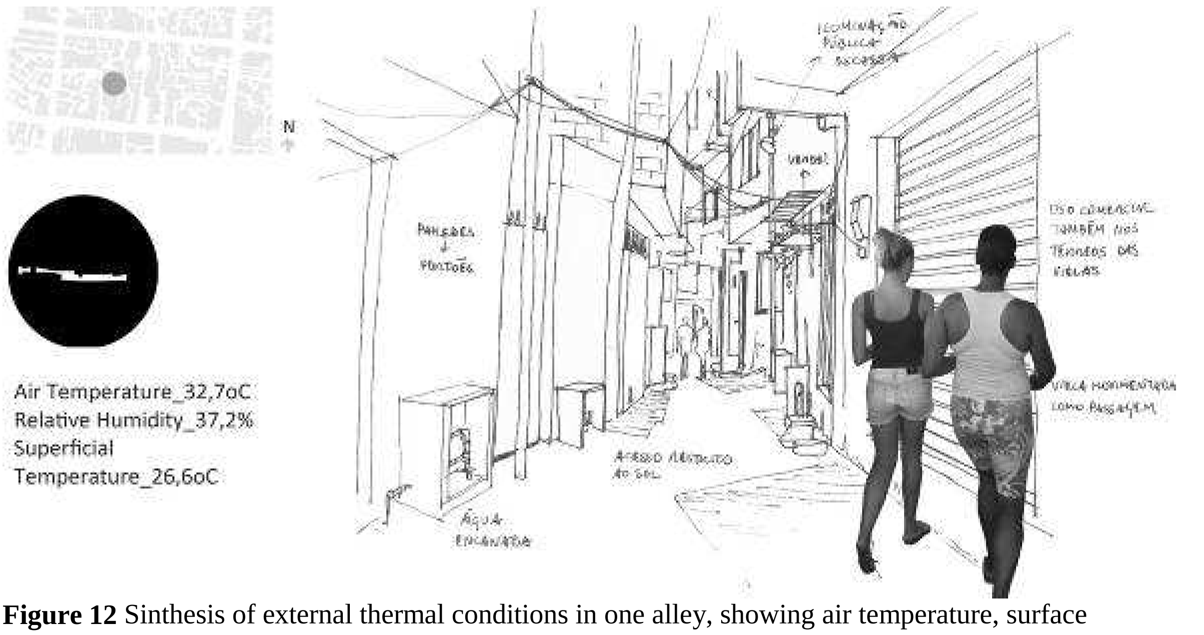


Figure 12 Sinthesis of external thermal conditions in one alley, showing air temperature, surface temperature, relative humidty and air movement on a hot summer day at 4:15 pm. Source: Pizarro, 2014.

Thermal environment in internal spaces

Measuraments of thermal conditions of an internal space were taken in one of the houses facing a main street. The exposure to solar radiation coupled with the concentration of internal gains and insufficient ventilation rates resulted in air temperatures as high as 40^{o}C in the living space (bringing together living and kitchen in one area) at 4 pm of a week day, when outdoor temperatures oscilated around 33 ^{o}C (figure 13). The way windows are design, protection against solar gains would inevitably block the already limited air ventilation rates, so as a common practice, windows are kept open by the occupants during the day in order to provide some air movement, however, inefficient to control the rise of internal temperatures. At nitgh, internal temperatures drop up to 10 ^{o}C. It is known that windows are kept open during the night allowing for nitgh time cooling of the internal spaces and the building fabric of brick walls and concrete block ceilings. However, during the internal temperatures quickly go up to 35^{o}C and than 40^{o}C degrees during the 1st half of the day. In principle, solar protection and higher ventilation rates would improve such conditions.

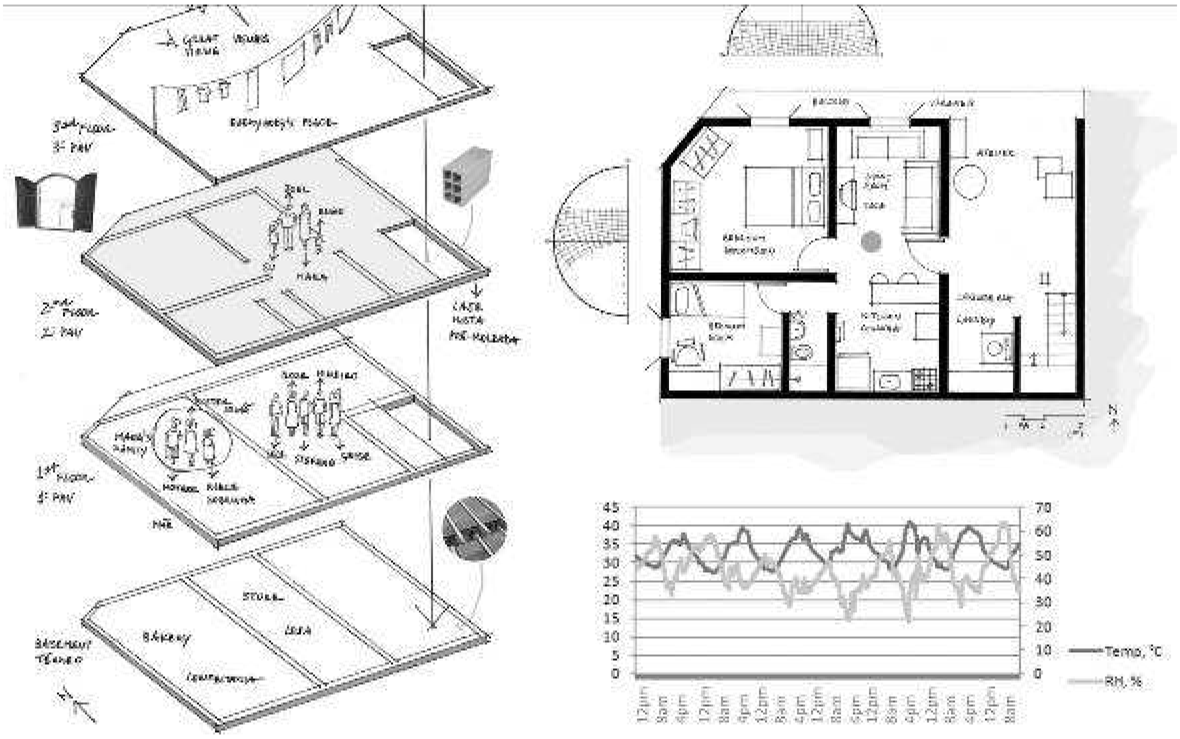


Figure 13 Measuraments of air temperature in a residencial unit with a multistory building, facing a main street in *Paraisopolis*. Source: Pizarro, 2014.

ENERGY DEMAND: THE CASE STUDY OF *FAVELA MORRO DA USP*

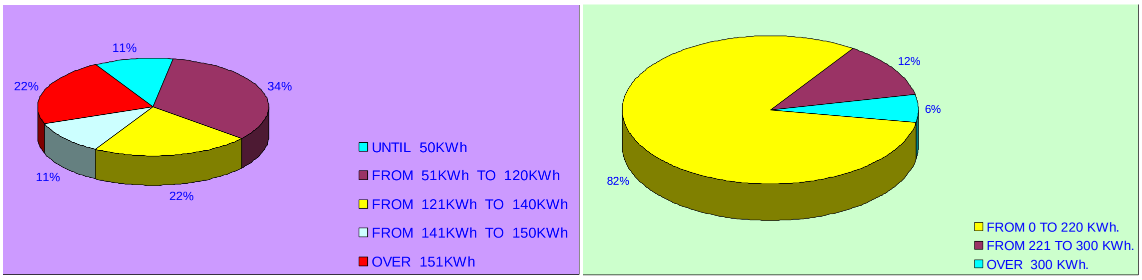
The main type of energy consumed in the building sector in Brazil is electrical. The electricity consumption in the Brazilian residential sector represented 20% of the total in 1991, whilst in 2000 it grew to 27% (CCPE, 2004). In the group of cities of the South-East region of the country, where São Paulo is located, the main energy consumer is the fridge with approximately 30%, followed by the electric shower with approximately 26% and the artificial lighting with approximately 10% (Guisi *at al*, 2007). Looking at the electricity consumption in a typical middle class residence in São Paulo, this trend results in a average of 117Kwh/ m^2 month, in a residence of around 70m^2 (BESP, 2009). Compared with data from the National Energy Balance (BEN, 2010), the numbers relating to residential energy consumption in São Paulo are very close to the national average, being 113kWh/m^2. It is worth noticing that almost 40% of the residential energy consumption range from 100 to 160kWh/m2, with an average of 3.2 people per family (BEN, 2010).

Looking at the case of *Favela Morro da USP*, although almost 70% of its population have an monthly income below five minimum wages (between U$545,00 and U$1.818,00), proving the hypothesis that the consumption of electricity in consolidated favelas has a similar pattern to that from the local middle class homes in Brazil (Pizarro, 2014). This is due to the increasing acccess to affordable appliances. As the enegy demand grows in consolidated slums, as in *Morro da USP*, the provision of electricity becomes problematic for two reasons: the difficult access to the residential units, due to the informal use of land and compact nature of the built envionemnt, and the dynamic changes of the slums' social and physical structures. The precarious nature of living combined with great expansion of self-built units and subdivisions of one residence in multiple ones (figures 14 e 15), imposes a fundamental challenge to the task of checking and monitoring the consumption of the different buildings and families.

In *Favela Morro da USP* it is common to observe a single residencial unit housing two or more families, which would demand different electricity meters. In a number of cases, the informal sharing of the spaces and domestic appliances between families makes the division in electricity consumption of different families not clearly distinguishable and difficult to be priced.

Figures 14 e 15 On the left, the precarious electricity grid running in front of windows in favela *Morro da USP*.On the right, the multiple electricity meters installed in one residential building.

In this context, the total monthly energy consumption by household cannot be translated into kWh/m^2, once the area occupied by each household is a constant changing factor and cannot be simply identified by the plot ratio of the building. In order to present a clear energy consumption profile, the figures chosen to illustrate the electricity consumption in the case study of Favela *Morro de São Paulo* refer to only one month, corresponding to the biggest number of households being registered in the year of the fieldwork, May 2013 (Pizarro, 2014). The fieldwork showed that for 82% of households the threshold of electricity consumption is 200kwh per month, thus achieving the Social Discount Rate Low Income, created by the Federal Government in January 2010 (figure 16 e 17). The new social tariff of electricity consumption promoted discounts for social housing, varying between 10% a 65% in cases which the monthly family income per capita is equal or less than half of the national minimum wage. The degree of discount is associated with the household consumption, varying from the minimum of 30kWh per month for the maximum discount of 65%, to 202kWh per month for the minimum discount of 10%.



Figures 16 e 17 Energy consumption in the residential buildings of Favela *Morro da USP* in May 2013. On the left, the percentage of households below 50kWh and above, including demands over 151kWh. On the right, a detail assessment of consumption above 1501kWh, with 82% up to 220kWh, the threshold of the Social Discount Rate Low Income, and percentage of units above.

With respects to life-style, it is important to note that the population of consolidated favelas such as Morro de São Paulo, where addresses have been established based on to energy and sewage bills, has led residents to have access to bank credit and, therefore, to domestic appliances existing in a typical middle-class residence in Brazil (TV, microwaves, stereos, computers, irons, electric shower, washing machine, etc.). The gradual increase in the buying power of the low income sector in Brazil, which is visible and practiced in the city of Sao Paulo is among the factors that justify the levels of energy consumption shown in figures 16 and 17. In order words, the oficialization of energy consumption has become an efficient way of socioeconomic inclusion. Nevertheless, the challenges to access all residential units, provide electricity with a safe grid and measure the consumption of individual households remain. Furthermore, the compact urban fabric of the favela results in a highly-concentrated energy demand. In this scenario, to avoid risks of power supply for electricity, implementation of conventional infrastructure facilities could be planned with the introduction of the so called alternative or ”green” technologies, such as solar collectors for water heating and photovoltaic cells for electriccity.

FINAL CONSIDERATIONS

Access to electricity became an effective means of social inclusion. In that sense, since the energy bill is associated with a formal address, within an informal urban settlement, the households have the minimum requirements to take part in the formalozed market of goods and appliances, including the access to financial credits. In addition to that, contrary to the misconception that low income families inherit inefficient domestic appliances (or have none at all), the reality in consolidated *favelas* is that there is a trend of energy consumption similar to those of the overall residential sector in the region. On the other hand, different from the formal part of the residential sector, the energy supply in *favelas* faces the challenges brought by the constant growth and changing of the physical environment, including the horizontal and vertical expansion and multiple subdivisions of one building in several households.

From the point of view of broader environmental issues, whilst energy consumption shows the increasing buying power of low income families living in *favelas* in São Paulo, the comfort of the inhabitants inside the buildings and the environmental conditions of open public spaces do not offer good quality. In this respect, the performance of the local built environment of the *favela* with the principles of environmental design for the specific climate of São Paulo needs to be further improved both for indoor and outdoor spaces, if quality of life is to be provided beyond access to energy.

ACKNOWLEDGMENTS

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Sustainable water management in buildings, an affordable approach. Case Study: Terra Bio-Hotel Project, Medellín, Colombia

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ABSTRACT

Water management model in cities is based upon large-scale systems which take water form external watersheds located dozens to hundred kilometers to the municipalities they supply. Water is treated to drinking standards despite the intended use, leading to wastewater which is discharged back to the environment through sewer systems, often without previous treatment, being an important source of environmental pollution and public health hazards. Meanwhile rainwater is considered a problem, being collected from roofs and streets to be also disposed in sewers as other kind of wastewater. Although water technologies have evolved, this model has virtually remained the same since the ancient Rome, twenty centuries ago. A paradigm shift is urgently required and buildings must be in the center of this transformation. Terra Bio-hotel, a 41 room hotel located in Medellín is a project designed and being built with sustainable water systems, integrating low consumption devices, rainwater harvesting, greywater recycling and groundwater catchment. Although the building is connected to the municipal service, altogether these strategies allow the project to function as net-zero as for water is concerned. As expected, the water management scheme of this project is considerably more expensive than a conventional one. Nevertheless, when operation costs are compared to conventional water fares, it appears that investment costs are returned in five years, demonstrating eco-efficiency to be an economically sustainable choice at this scale.

INTRODUCTION

As world urbanization increases so does the pressure upon water resources. This is particularly true for Latin America and the Caribbean, where 80% of population lives in cities which are dependent on external water sources to supply, where wastewater treatment is low and vulnerability to urban floods from storm water is high (Howe, Butterworth, Smouth, Duffy, & Vairavamoorthy, 2012; World Bank, 2013)

This unsustainable condition is related to sectorial water frameworks where local governments, environmental agencies and water companies work for contrasting agendas and measure their challenges and achievements by divergent indicators, whereas citizens, private sector and public institutions remain as passive users, with no say on water governance (Domenech, 2011; Bedoya, 2011)

Since urban water is mainly used and polluted through building operations; water-efficient buildings are a reasonable starting point to give users a more meaningful role on water governance. This paper describes and discusses the water management model implemented on Terra Bio-Hotel Building in Medellin – Colombia, as a study case, whose comprehensive adoption on other building projects in Latin America and other regions may make a significant contribution for cities to become less dependent, more efficient, healthier, less contaminant, more resilient and more sustainable with regards to water (Howe, Butterworth, Smouth, Duffy, & Vairavamoorthy, 2012).

OBJECTIVE

The aim of this applied research was to conceptualize, develop and implement a model for water efficiency on a real scale building in Medellín – Colombia and to forecast the expected environmental and financial cost-benefit ratio in order to provide governs, planners, designers and constructors a framework to make informed decisions on sustainable water management schemes.

PROCESS APPROACH

Case study

Terra Bio-Hotel is a medium size hotel building with 41 rooms and 2400 m^2 built area, looking to be distinguished for its environmental standards at both construction and operation phases, giving host a differential factor concerning architecture and technical facilities.The project is set in Medellín, biggest of ten municipalities assembling a metropolitan area called the Aburrá Valley, inhabited by 3.5 million people.

Water management data for Aburrá Valley

Information concerning water management for Aburra Valley was collected and analyzed from local land and water plans, publications by local environmental authorities and local Water Service Company, as well as from technical relevant literature.

Water management systems for the case of study

Prior to hydraulic design, two water system schemes were pre-designed, analyzed and compared. System 1 is conventional, whereas System 2 is an alternative system proposed to lower the environmental impacts related to water demand and wastewater disposal along operation phase of the building (see figure 1).

Figure 1. Water treatment systems installed at Terra Bio Hotel

Water treatment plants for System 2

In order to fulfill the principles for System 2, two treatment plants are required: one plant to treat grey water to be reused on activities that do not require drinking-quality water, such as toilet flushing, general maintenance and irrigation of green areas; the other plant is to treat rain water and groundwater up to drinking-quality standards, to be used for showers and faucets. Both rainwater and groundwater were previously sampled and tested for compliance to water quality regulations set for water sources intended for domestic supply (data not shown).

Cost-benefit analysis

Financial investment costs for pre-designs of each hydraulic system scheme were calculated. Water demand is estimated as established for hosting facilities by Colombian regulations.

Environmental costs-benefit analysis is based on the following indicators:

- Total water consumption (m^3/year)
- Dependency on water sources external to the watershed (m^3/year)
- Wastewater discharge (m^3/year)
- Storm water discharge (m^3/year)

RESULTS

Water in the local context: Water management model in the Aburrá Valley

Table 1 provides main data concerning water management in the Aburrá Valley, which is highly dependent on external water sources despite of its high water yield. Most urban population has access to water supply, but unaccounted for water is high. Most population also has access to basic sanitation trough connection to a sewer network, although the level of wastewater treatment remains low. New wastewater treatment facilities are under construction and will be fully operating by 2015 though. Due to such investments, sanitation is charged higher than supply. Groundwater is an abundant source and it is used, mainly by industry, but total withdraw is unknown. For building sector, such abundance becomes a problem since parking lots and basements get below the water table, thus water has to be pumped out and discharged into the sewer system which is charged at sanitation fares, this would also be the case for Terra Bio Hotel project (see table 1) (Municipio de Medellín, 2014; URBAM, Área Metropolitana del Valle de Aburrá, & Municipio de Medellín, 2011)

Table 1. Main Data Describing the Current Model for Water Management in the Aburrá Valley

Parameter	Value
Water cycle balance	
Valley Area (km)	1250
Average precipitation (mm/year)	1672
Average evaporation (mm/year)	1172
Water yield (mm/year)	500
Water yield (million m^3/year)	625
Water supply	
Total water consumption from water supply (million m^3/year)	192
Dependency on external water sources –watersheds located outside Aburrá Valley- (%)	90
Unaccounted for water (%)	40
Volume extracted from external sources, considering unaccounted for water (million m^3/year)	288
Population served (% of total urban population)	99
Wastewater	

Combined sewer network (%)	60
Sewage currently being treated (%)	20
Water reuse	0
Population served (% of total urban population)	99
Rainwater	
Rainwater use (%)	0
Conventional drainage (%)	100
Groundwater	
Recharge (million m^3/year)	400
Water table depth on the alluvial plain (m)	4 - 8
Groundwater extraction (million m^3/year)	unknown

Environmental costs comparison

Figures 2 and 3 show a water balance conceptual model for System 1 and 2

System 1 consists of:

- 100% of water needs supplied by the local water company
- drinking-quality water is used for all purposes
- no reuse is considered
- rainwater is directed to sewer without use
- since parking lot base is below water table, groundwater is pumped in order to prevent floods and discharged into sewer with no prior use

Principles for System 2 are:

- water needs supplied from diverse sources
- water source defined according to required quality by use
- reuse is considered
- rainwater as well as groundwater are caught, treated and used

As shown in figures, System 1 produces more environmental impacts than System 2. Water demand for the two systems is the same, but system 1 requires 40% more water, since it fully depends on external sources (table 1). System 1 also produces more pollution since groundwater and rainwater are not harvested but just discharged on sewers and grey water is not reused.

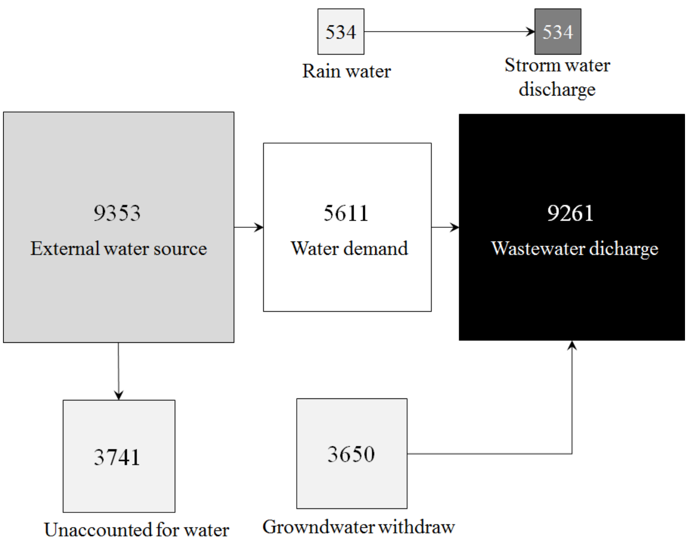

Figure 2. Water balance conceptual model for conventional water management system, System 1. Numbers are expected volumes expressed as m3/year. Frame fill colors are related to water quality: white = high quality, black = low quality.

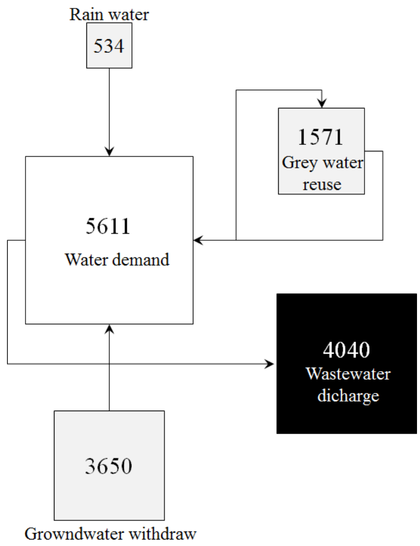

Figure 3. Water balance conceptual model for alternative water management system, System 2. Numbers are expected volumes expressed as m3/year. Frame fill colors are related to water quality: white = high quality, black = low quality.

Due to the use of groundwater and rain water as well as the reuse of grey water, implementation of System 2 not just significantly reduces pollutant discharges from the project but also would eventually allow it to be fully independent from external water sources (see figure 2), in fact, volume balances for System 2 shows that the project may produce more water than it actually needs (see table 3)

Cost-benefit analysis

Investment cost

Table 2 lists the investments required for hydraulic installations under Systems 1 and 2 schemes. Implementation of the efficient water management option costs as much as 38% more than implementation of the conventional system.

Table 2. Investment cost comparison between System 1 and System 2

Item	Cost for System 1	Cost for System 2	Description
Water pumps	$ 28.947	$ 32.632	On System 2 an additional pumping system for grey water supply is required, but the pumping capacity required for drinking water supply gets reduced
Storage tanks	$ 10.526	$ 12.632	On System 2 an additional storage tank is required for grey water supply, but the storage capacity for drinking water supply tank gets reduced
Drinking water network	$ 9.944	$ 5.966	Drinking water supply network gets shorten on System 2, since part of it is replaced by the grey water supply network
Grey water supply network	$ -	$ 6.526	It only applies for System 2
Wastewater network	$ 13.158	$ 11.053	It gets reduced on System 2 since part of it becomes greywater supply network
Rainwater network	$ 6.642	$ 8.105	Rainwater network becomes longer on System 2 in order to reach treatment system
Treatment systems	$ -	$ 18.421	Only applies to System 2

Sum	$ 69.217	$ 95.334	
Difference	$ 26.117		

Operational costs

Table 3 compares both financial and environmental operation costs for the two systems, water treatment per cubic meter under System 2 costs just 10% of the fare charged on water supply and 6% of the fare charged on sanitation. Hence the cost of using rainwater is 10% of conventional supply. Groundwater use and grey water reuse have a further benefit since these volumes do not get charged for sanitation. Altogether operational cost for System 2 is 40% of operational cost for System 1, allowing full return of the additional investment costs by year 3 of operation. On a 30 year lifecycle basis System 2 leaves the project a US $ 261000 net benefit over System 1 (see figure 4).

Table 3. Operation cost comparison between System 1 and System 2

Item	**Symbol**	**Metric**	**Value**	
Number of romos	R		41	
Water demand (m3/room/day) According to Colombian regulation	wd		0,5	
Occupation index for hotels in Medellín (%)	oi		75%	
Daily water demand (m3/day)	dd	r*wd*oi	15,4	
Total water demand (m3/year)	WD	dd*365	5611,9	
Total rainwater (m3/year)	RW	Average precipitation from table 1 * On ground building area	534,4	
Total groundwater withdraw (m3/year)	GW	From case study description	3650,0	
Grey water reuse (m3/year)	GyW	Estimated as 28% of water demand	0,0	1571,3
Dependency on water sources external to the watershed (m3/year)	DEW	System 1 = WD/(1-Unaccounted for water from table 1) System 2 = WD - GW - RW - GyW	9353,1	-143,8
Total wastewater discharge (m3/year)	WW	System 1 = WD + GW System 2 = WD - GyW	9261,9	4040,6
Supply water costs (US $/m3)	wc	Sytem 1 = supply charges from table 1 System 2 = by treatment plant providers	0,86	0,08
Supply anuual costs (US $/year)	SWC	WD*wc	4.826	443
Sanitation charge (US $/m3)	sch	From table 1	1,3	
Sanitation annual costs (US $/year)	SnWC	System 1 = (WD+GW)*sch Sytem 2 = (WD-GyW)*sch	12.040	5.253
Total water system operation costs (US $/year)	WOC	SWC + SnWC	16.867	5.696
Difference				(11.171)

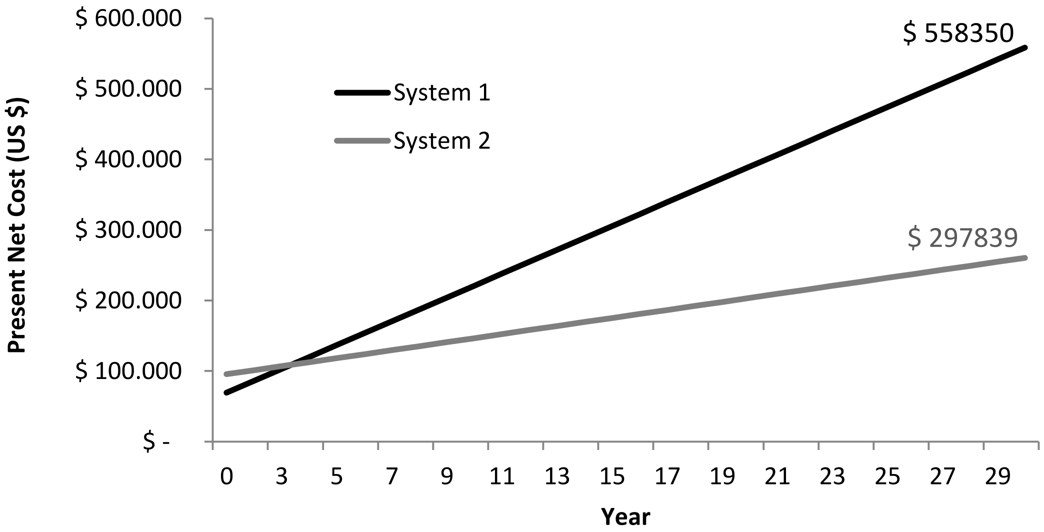

Figure 4. Comparison of net present costs for the two systems

In spite of requiring higher investment costs, an alternative ecoefficient water management system shows to be the best choice in order to reduce both economic and environmental costs for this case of study. Dependency on external water sources and storm water discharge might get down to zero, as total water demand and wastewater discharge might reduce down to 45% at a financial present net cost of 53% as compared to a conventional water management system.

DISCUSSION

Aburrá Valley urban water management is characterized by a high dependency on external water sources, a high unaccounted for water index, a non-regulated groundwater withdraw, a low level of wastewater treatment and no policies on storm water discharges, leading to a vulnerable, inefficient, pollutant system. Most Colombian and Latin-American cities might be described likewise (Howe, Butterworth, Smouth, Duffy, & Vairavamoorthy, 2012; Domenech, 2011)

These concerns are being addressed from centralized approaches such as upgrading supply systems and building new wastewater treatment facilities, but the role of end users is not yet being considered a key issue. This paper shows that buildings, as end water users, would significantly improve the whole system performance by reducing dependency, inefficiency and pollution, while significantly reducing operational costs, leaving in fact economic benefits on a lifecycle basis (Penagos, 2007; Bedoya, 2011)

The model described here may be adopted by building projects along the Aburrá Valley, similar approaches might be analyzed, developed and implemented in other Colombian and Latin-American Cities, which will continue expanding in coming years under uncertain scenarios concerning incidence of climate change on water availability, which is already a critical threat to human development in the region. This study would be also a useful base for governments in order to promote policies and regulations encouraging sustainable water management for healthier cities (Howe, Butterworth, Smouth, Duffy, & Vairavamoorthy, 2012; Penagos, 2010)

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Session 6D : Tools and methods/ framework

PLEA2014: Day 2, Wednesday, December 17
14:10 - 15:50, Trust - Knowledge Consortium of Gujarat

Energy certification process in Chile: steps to dynamic simulation of buildings' energy performance.

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ABSTRACT

This paper presents comparative studies among dynamic simulation and steady-state evaluation (degrees – day) for residential building certification in Chile. Energy certification is still young in the country, but its impact in reduction of thermal demand could be very high. The main problem seems to be the use of simplified methods, which have not been tested for all the country's climates. Chile has a lot of very different scenarios, from the Atacama Desert to the extreme south Patagonia, which are not always well represented by daily average temperatures. The Chilean National Energy Certification System started in 2013 to qualify residential buildings, most of them by using steady-state evaluation. However, in the northern deserts of the country, dynamic simulation is needed to permit a quality work of certification. This paper presents 21 dwellings located in the city of Antofagasta, simulated by using normative software CCTE and also evaluated by using the simplified normative method developed by the Government. Results shows important differences in the final results, both in terms of estimated thermal demand and final etiquette obtained. Steady-state evaluation definitively seems to be not very useful for the desert climate, even in the coast region, were thermal oscillation is relatively low because of the Ocean's effect.

INTRODUCTION

In 2013, The Chilean Government introduced the National Energy Certification System for Dwellings. The system is voluntary but the Ministry of Housing has the intention to make it mandatory by 2015. The system assigns two different energy classes: one relates to architectural parameters (envelope, form, orientation) and the other relates to systems efficiency (heating system, solar energy use for hot water, and photovoltaic panels for electric generation to be used in electricity). The first group of accredited evaluators started to certify social and private projects in order to test the results of system implementation. Two options are managed to estimate heating energy demand: simplified steady state option that uses degree-day concept and fully dynamic simulation by using CCTE software (MINVU, 2012).

Chile is a country that extends from a latitude of 18 South (Arica) to 56 South (extreme south Patagonia). For this reason, in Chile all kind of climates can be detected, from arid to cold, from mountain to tropical. However, the national certification system only considers heating needs of the central and southern zones. The climate classification developed to use the degree-day concept divides the country in seven zones, plus two sub-zones (extreme south and north), not considering day-night thermal oscillations to distinguish locations with the same average temperature but very different maximum and minimum temperatures (MINVU, 2008b).

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Thermal zones defined by Ministry of Housing are different with respect to climate zones defined by norm NCh 1079 (2008) that consider longitude and altitude as well as latitude defining Chile's climates. This contradiction has been mentioned in the country as one of the most important limitations of the National Energy Certification System; see for example Bustamante (2009).

In northern regions of the Country, the system does not appear to be completely useful, because of a lack of consideration in regards to cooling demand and because of the simplified options, which don't consider thermal inertia of construction. To reach a good energy class (starting from "D"), in the north zones dwellings have to have less than 75% of the thermal demand and less than 80% of total energy consumption in respect to the reference building. The reference building has the same size and form of the analyzed building, but mandatory compliance in materials and average orientation.

In addition, low heating demand in the North leads to poor energy labeling, because of the limitation in reference building demand (if reference building has an estimated heating demand lower than 30 kWh/m2, thermal performance is not calculated and only hot water and electricity are considered to assign the energy class). To investigate discrepancies between the simplified method and dynamic full simulation, a social dwelling project was selected as a case study.

METHODOLOGY

In this research, 21 dwellings are evaluated by using steady-state method and also simulated by using dynamical software CCTE. Then, a comparison of results is done, searching for differences in heating demand and in the final energy class assigned to each dwelling.

Case study "Tres Marías"

Dwellings located in the city of Antofagasta, 23° south and 70° west, at Sea level. Figure 1 shows project emplacement and dwelling orientation (courtesy of SERVIU). Site has a little slope, resulting in shadows on the east side and solar access on the west. Moreover, on the east the first line of mountains protects houses from solar access in the morning. On the south and north other buildings generate shadows at specific hours of the day in summer and winter, respectively.

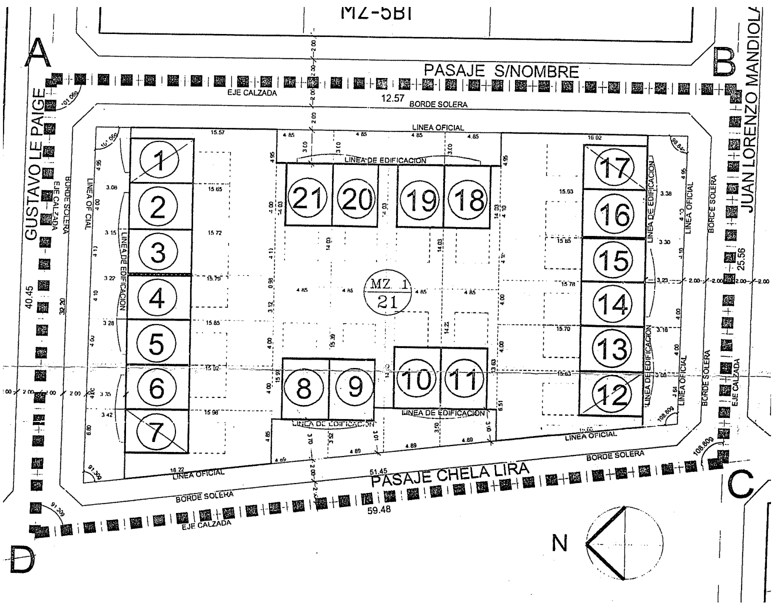

Figure 1 House's emplacement and orientation

Figure 2 shows architectural distribution on two floors. Houses have a floor surface of 45 m2 (22 m2 on each floor). Figure 3 shows the facade.

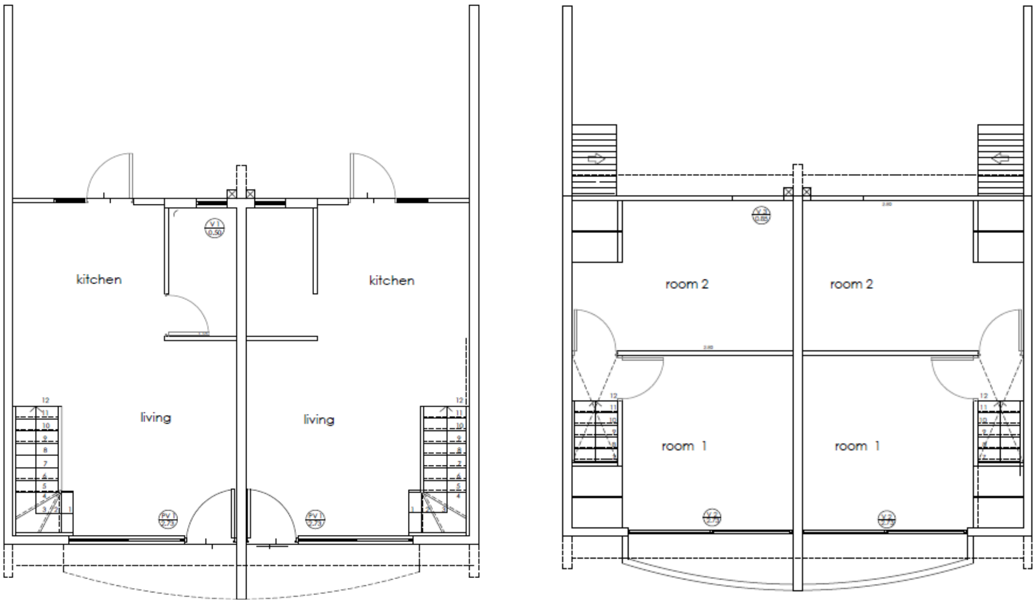

Figure 2 Ground and first floor plan

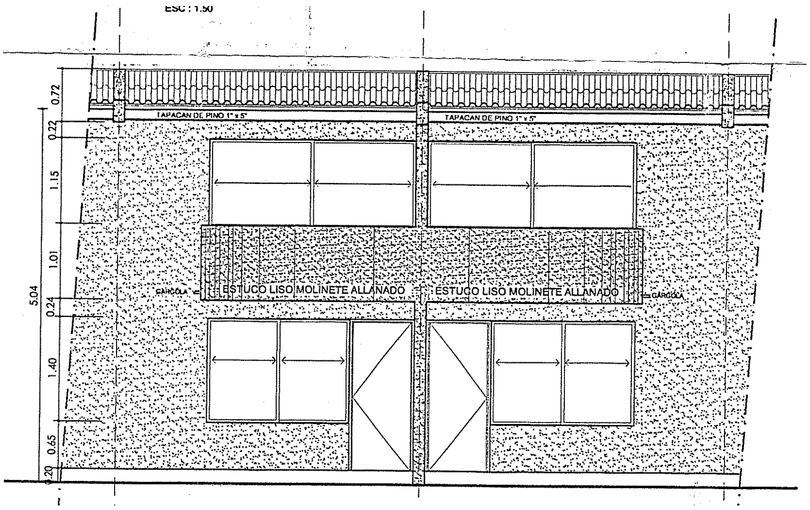

Figure 3 Facade of the dwelling

Materials and equipment

Construction uses two kind of vertical walls: block walls and external board walls. Block walls are composed by 150 mm of concrete plus 20 mm of insulation (polystyrene) and 10 mm of ceramic finishes. Thermal transmittance is 1.32 W/m^{2}K. External board walls are composed by OSB (11 mm) plus 40 mm of insulation (rock wool) between steel profiles, plus another 20 mm of insulation (polystyrene) and 10 mm of ceramic fihishes. Thermal transmittance is 0.88 W/m^{2}K. Roof is made of block work (130 mm) plus 100 mm of insulation (rock wool). Thermal transmittance is 0.38 W/m^{2}K. Floor is composed by blockwork. Door is made of pressed wood, thermal transmittance 3.7 W/m^{2}K. Windows are single glazed, with thermal transmittance of 5.3 W/m^{2}K and solar factor 0.87. Table 1 resumes transmittance values of construction elements. Transmittances have been calculated as indicated in Chilean norm NCh 851 (2008), NCh 853 (2008) and Thermal Norm of MINVU (2008a).

Table 1. Walls and windows properties

Wall	Transmittance (W/m^2K)	Thickness (mm)	Solar factor (%)
Blockwork wall	1.32	180	0
Board wall	0.88	81	0
Roof	0.38	230	0
Floor	3	230	0
Door	3.7	50	0
Window	5.3	6	87

Dwellings do not have heating systems. Hot water system is electric boiler with 150 dm^3 deposit. No solar panels are considered for hot water or electricity production. Electricity is considered in certification as standard system. No other appliances are considered.

RESULTS AND DISCUSSION

Steady state evaluation

21 dwellings were evaluated, first by steady state method. The system considers a reference building that has the same form of the project, compliance materials and average orientation. Reference building has in most cases a heating demand of less than 30 kWh/m^2 year. As a result, most dwellings facing south or north are not evaluated in terms of heating demand. Only the dwelling numbers 1, 7, 12 and 17 are evaluated. East and west dwellings are also evaluated, because of the higher exposed surface. All dwellings are evaluated in terms of hot water production (electric system).

In the Chilean system, the architectural energy class assigned to a dwelling depends on the thermal zone where the dwelling is placed. In northern deserts, to attain an “E” label, the dwelling must have a thermal demand between 75 and 110% of the reference dwelling. Reference dwelling has the same form, average orientation and minimum standard compliance for materials. To reach a “D” class, the dwelling must have a thermal demand between 55 and 75% of the reference. To obtain a “C”, thermal demand has to be between 40 and 55%; to obtain a “B”, between 30 and 40% and to earn an “A”, between 0 and 30%.

System energy class depends on the primary energy consumption; therefore electrical systems for hot water are normally evaluated as “G”. To obtain an “E” label, primary energy consumption has to be between 80 and 110% of the reference; to obtain a “D” has to be between 60 and 80%; to obtain a “C” 45 to 60%; “B” 30 to 45% and “A” less than 30%. This indicator is not dependent on the thermal zone as the heating demand. Table 2 resumes the label correspondence for thermal zone 1 (northern coast deserts of Chile).

Table 2.

	Energy percentage respect to reference building				
	Label A	**Label B**	**Label C**	**Label D**	**Label E**
Demand	0-30	30-40	40-55	55-75	75-110
Consumption	0-30	30-45	45-60	60-80	80-110

Results are resumed in table 3: most of the dwellings have class energy “G” or “F”. The main reason of this result is the impossibility of evaluating dwellings if reference has less than 30 kWh/m^2 year heating demand. However, the result is illogical, because the dwelling has better values of transmittances than reference building, then a better class is expected (if dwelling has the same demand of the reference, class “E” is assigned).

Table 3. **Steady state evaluation results**

Dwelling	Orientation	Architecture	Systems	Heating demand (kWh/m^2 year)	Heating reduction (%)
1	N	D	E	22.0	42
2	N	/	G	/	/
3	N	/	G	/	/
4	N	/	G	/	/
5	N	/	G	/	/
6	N	/	G	/	/
7	N	D	E	22.2	40
8	W	E	F	39.4	15
9	W	E	F	40.2	12
10	W	E	F	38.2	19
11	W	E	F	41.1	10
12	S	E	F	41.7	2
13	S	/	G	/	/
14	S	/	G	/	/
15	S	/	G	/	/
16	S	/	G	/	/
17	S	E	F	39.7	5
18	E	E	F	40.1	8
19	E	E	F	36.4	17
20	E	E	F	30.1	21
21	E	E	F	32.6	19

CCTE simulation

CCTE evaluation uses dynamical simulation of the real and the reference buildings. Because in this case the reference building has the same orientation of the analyzed one, four simulations have been done and reference building results are the average of the four orientations considered (N, S, E and W). Figure 4 shows the CCTE model of East/West dwellings.

All dwellings are analyzed because in this case the reference building has a heating demand higher than 30 kWh/m^2 per year. In general, analyzed dwellings are better than the reference in terms of heating demand (between 20% and 30%) and very close to the reference in terms of energy consumption, because of the low efficiency of the electric boiler.

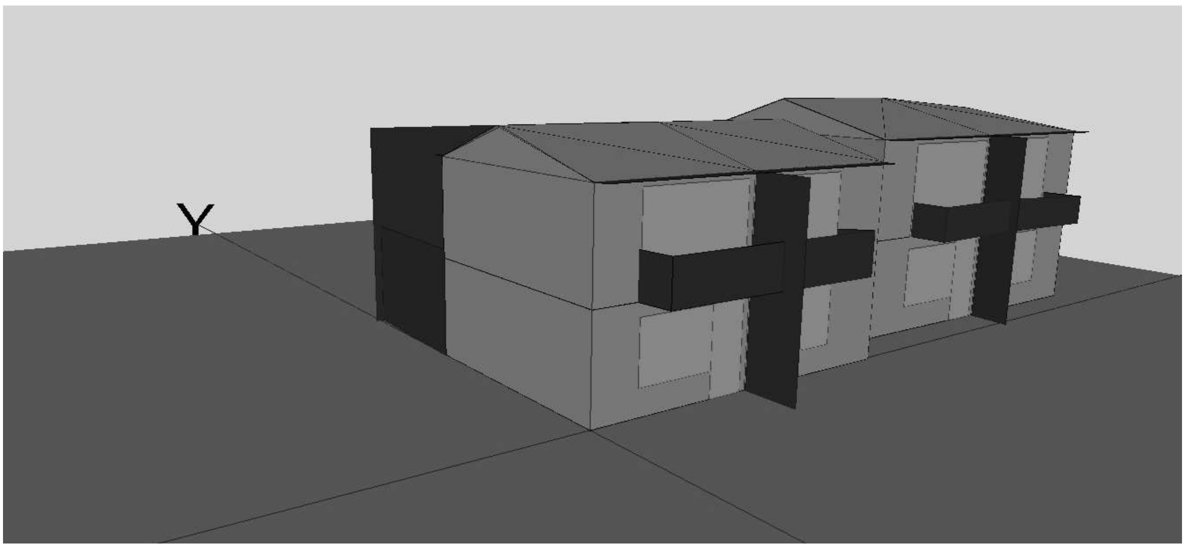

Figure 4 CCTE model used in simulations

Results in this case are more consistent, because all dwellings have a better or at least the same energy class of the reference building. The reason is that dynamic simulation leads to more than 30 kWh/m^2 year of heating demand, which permits the obtainment of the architecture class. Table 4 summarizes the results.

Table 4. CCTE evaluation results

Dwelling	**Orientation**	**Architecture**	**Systems**	**Heating demand (kWh/m^2 year)**	**Heating reduction (%)**
1	N	D	E	34.1	37
2	N	D	E	25.4	31
3	N	D	E	24.8	33
4	N	D	E	23.6	37
5	N	D	E	25.8	34
6	N	E	E	32.2	26
7	N	E	E	36.1	22
8	W	D	E	35.3	36
9	W	E	E	36.1	24
10	W	E	E	34.9	19
11	W	E	E	34.2	27
12	S	E	E	35.9	19
13	S	E	E	27.9	19
14	S	D	E	26.3	28
15	S	E	E	26.3	20
16	S	D	E	25.5	30
17	S	E	E	31.9	23
18	E	E	E	40.1	26
19	E	D	E	32.2	34
20	E	D	E	30.1	32
21	E	E	E	35.5	26

North-facing dwellings have “D” class assigned (most of them), because of better solar access in winter. Some south-facing dwellings also have “D” class because they reach 25% of demand reduction.

Steady-state evaluation leads to unreliable results in most considered cases: because of low heating demand of the climate zone, architecture is not evaluated and only electrical system for hot water production is considersd. Dwellings that have better performance than the reference building (between 20% and 30% considering heating demand) are classified as “G” or “F” because of the low efficiency of electric boilers for hot water production. Only two of the north-oriented dwellings are evaluated and classified as “D” in architecture and “E” in energy consumption. On the other hand, CCTE dynamic simulation lead to more realistic results and all the 21 dwellings are evaluated, obtaining architectural class “D” or “E” (depending on energy saving: to obtain “D” class energy saving has to be more than 30%). In this case, all consumption classes are “E”.

CONCLUSION

The energy certification process in Chile is focused on heating demand reduction, the most important problem in southern regions of the country. Northern regions are considered to be temperate, and building overheating is nowadays resolved by natural ventilation. However, some considerations have to be made. First, the energy certification system has two options, simplified evaluation and dynamic simulation. In the South of Chile, both methods lead to the same energy class in most cases, but in the North many cases have different classes, as discussed in this paper. Thermal mass effect and especially 30 kWh/m^2 limitations in reference building to evaluate architecture thermal demand are problems in the current system.

Second, natural ventilation is supposed to be sufficient to cool buildings, but in the future some urban climate changes could modify this situation. Global warming in northern Chile will probably be very high (up to 5 degree increase of temperature in the middle of the century), heat island effect will be present in cities of middle size, tall buildings construction in the first coast line will act as a blockage to sea wind. All these factors are clearly indicated as a danger for overheating in built environment; see works of Chilean Government (2013), Palme (2014), Valenzuela (2013).

Finally, economic development of the country, especially of the northern mining zones, will have the consecuence that people will search for better comfort standards, and install air conditioners to avoid overheating in residences. This could be very dangerous, because it will add to an increase in global warming. In this conclusion, it appears very important to recommend the introduction of a dynamic system of energy certification, taking into account heating and cooling demand, as well as the removal of the 30 kWh/m^2 limitation in reference building heating demand.

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Effects of Aggressive Energy Efficiency Regulations on an Unprepared Building Sector using Uncertainty Analysis

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ABSTRACT

Building Assessment Tools (BATs) are widely used to estimate the performance of building and to assist designers in making decisions. As building codes and rating systems move from prescriptive to performance-based metrics, BATs are increasingly used to show compliance. BATs use computational methods and the results are mostly in a single annualised metric. However, the scientific community has shown that aleatory factors such as occupant behaviour and weather make the potential energy use of a building far from being a single deterministic value. Also, it is known that there is a significant deviation between predicted (at design stage) and actual energy use in buildings. These variations reduce the credibility of the predictions, questioning the acceptance of BATs results without considering underlying errors. This problem is amplified in developing nations because of under-policed construction sector. To address this, our work analyses uncertainty in a typical air-conditioned multi-storey residential building's performance in Delhi and shows implications of variable inputs in the results.

The paper first reviews the use of BATs and existing studies on simulation uncertainty. Then uncertainty is evaluated in energy simulation of a sample building, including effects of inconsistent and construction practices. EnergyPlus is then fed values sampled (by Monte-Carlo method) from probability distribution functions of inputs (building fabric and operational parameters). Further sensitivity and uncertainty analysis of the results is performed. From the 3500 simulations, the most sensitive inputs found were internal gains; cooling setpoints and infiltration. The variation in cooling demand and discomfort hours is more than double between the best and worst case.

INTRODUCTION

Anthropogenic activities in the last decades have altered climatic stability, water cycles and natural habitats. At the time of writing, atmospheric CO_2 concentration is 399 ppm (Tans & Keeling, 2014) (Mauna Loa Observatory); 37% more than the highest concentrations in 8,00,000 years (EPICA DATA) (Lüthi, D., et al., 2008). The annual mean surface temperatures are rising due to greenhouse gasses

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(GHG) concentration increase. It is estimated to rise by 0.3 to 4.8 in next 100 years (IPCC, 2013).

Governments around the world are evaluating the impacts of climate change on their economies. The Indian economy could be considered as climate sensitive as many sectors are wholly or partially dependent on seasonal weather cycles. Indian meteorological data shows a 0.4°C increase in the mean annual air temperature in the past 50 years (INCCA, 2010). Also, intensity and frequency of extreme weathers like heat waves, dry spells and heavy rainfall have increased (INCCA, 2010). Data assessments indicate warmer climates in India, with temperatures rising by 2-4^{o}C by 2050 (INCCA, 2010).

Buildings have a significant impact on the environment. Infrastructural development of cities leads to rapid growths in construction, causing 25% of India's current carbon emissions (Parikha, et al., 2009). Buildings are responsible for 40% of energy use and 33% of GHG emissions globally (UNEP, 2009). The energy use in buildings includes operational and embodied energy and 80% of building's life cycle energy is by the former (Gregory A. Keoleian, 2008) (Chris Scheuer, 2003). Also, the building sector has the highest and most cost-effective potential for providing long-term, energy and GHG emission savings globally (IPCC, 2014). This has also been observed at a national level in India (PC : IEP, 2006). Building assessment tools (BATs) are widely used for detail assessment of energy use in buildings.

Buildings are complex systems and their energy use assessments dependent on many parameters. However, in most cases, these parameters are variable and not certain (Pettersen, 1994). These uncertainties arise due to lack of knowledge in simulation inputs, improper construction methods, approximate weather data and unpredictable occupant behaviour. Statistical analysis of energy simulations has been seen as a powerful tool in predicting this variability (MacDonald, et al., 1999) (Blight & Coley, 2013). In this paper, we assess the effect in outputs by the variation of some building design input parameters, which are regulated by energy saving related polices.

This paper begins with a background section reviewing: (1) the use of BATs for design decision making; and (2) existing studies that analyse uncertainty in simulation results. This is followed by assessing variations in input parameters in energy simulations of a residential building in Delhi, including the effects of construction processes used. The paper focuses on uncertainties in the fabric (i.e. thermal properties) and operational parameters. It concludes by performing uncertainty and sensitivity analysis of the input variables for the output of cooling and heating energy use and discomfort hours.

BACKGROUND

Use of Building Assessment Tools (BATs) for code compliance to reduce energy use in buildings

BATs are widely used to estimate energy performance of building designs. These tools assist designers in the decision making process by providing comparative and detailed assessments of building performance under various design conditions and strategies. Due to their capabilities to model building systems and physical phenomena in detail, they are used make predictions about the performance of a building under a wide range of scenarios. But, in most cases, these tools rely on input parameters that are either assumed or averaged to provide deterministic outputs, i.e. predict future scenarios that are known to be uncertain (Haldia & Robinson, 2011) (de Wilde & Tian, 2009) (Blight & Coley, 2013) (Ramallo-Gonzáleza, et al., 2013). This results in simulations that are fundamentally unrealistic and have shown to have errors exceeding 100% (Brohus, et al., 2009) (Demanuele, et al., 2010).

In the context of the move from prescriptive to performance-based building regulations (e.g. US building energy performance assessments (BECP:US DoE, 1991); and Energy Performance of Buildings Directive in Europe (The European Parliament and The Council of European Union, 2003)), deterministic outputs seem to be ill-suited to provide realistic estimates of future performance due to the well demonstrated stochastic nature of energy use in buildings (Page, Robinson, & Scartezzini, 2007) (Blight & Coley, 2013). Similarly, India's Energy Conservation Building Code (ECBC) (BEE, 2009) has a performance based compliance criterion (BEE, 2009). ECBC is partly mandatory and does not include residential buildings. Experience in other countries suggests that voluntary codes eventually make the transition to mandatory codes (National Action Plan for Energy Efficiency, 2009) (Liu, et al., 2010).

Apart from the issues of uncertain results due to deterministic nature BATs' results, construction techniques that are widely used in India might result in underperforming fabrics even when conforming to ECBC specifications. Uncertainty analysis (with the inclusion of construction process deficiencies) could provide a contextual picture, with a more robust understanding of the likely outcomes of measures in the ECBC.

Uncertainty and applicability of BATs

Most BATs use deterministic algorithms to predict a single value for the building performance. Actual prediction is more complex. Uncertainty in building simulations arise due simplifications in computation process and building complexity to reduce computing time; or because of unknown and erroneous input parameters (Clarke, 2001). Simplification generally occurs in inputs like weather data, material properties (like U-values), geometry etc. There, only the mean or most probabilistic values are used. This provides an unrealistic picture as value of each input can vary within a range of data. This theoretical simplification gives a range for the value calculated but not a credible result (especially when results depend on many such inputs). Adapted from Ramallo-González's PhD thesis (Ramallo-González, 2013) and other similar works, we classify the types of uncertainty into three groups:

1. Environmental: Uncertainty in weather data because of use of nearest weather station's synthetic weather file and uncertainty in prediction of changing climate.
2. Workmanship and quality of building elements: Differences amid the design and the real building: Conductivity of insulation and thermal bridges, infiltration amount or U-values of walls and windows.
3. Behavioural: Actual building occupant behaviour and usage patterns.

Additionally there is divergence in computation i.e. the approximation and uncertainty in computational formulas in the simulation tools. Above groups, describe the broad areas of uncertainty. Based on the reasons of existence they can also be divided in two types, aleatory and epistemic. Aleatory uncertainties represent the randomness nature of some variables. Epistemic uncertainties are due to lack of knowledge (Sandia Lab, n.d.). Uncertainties make it impossible to find, for some inputs, a value that is actually true; observed by Newton when building energy simulations were in their infancy (Newton, et al., 1988):

"…the choices of climatological data and occupancy patterns are not easy and, in many cases, there is no single correct value."

Assessment of uncertainties at all levels is required to get results with confidence intervals. It is the only way to have realistic assessments and a better understanding of energy simulation results. In this study, aleatory and epistemic uncertainties in groups 2 and 3 would only be considered.

Areas where consideration of uncertainty can play a major role are in energy-savings performance contracts and in certification and code compliance for green and ultra-energy efficient buildings (e.g. LEED Ratings, or codes like EPBD in Europe or ECBC in India.). Since BATs are used to inform and evaluate designs, there is a significant risk (could be financial or of occupant comfort) if the real and predicted performance vary. Additional information about the uncertainty (like confidence intervals) would facilitate a more informed decision by the designer. Therefore, the argument of this paper is to prove how BATs should not be relied upon in a deterministic manner but in a probabilistic way, to provide the designers with stochastic indicators of the future performance or demand of the building. In this paper, we have used these indicators to verify the impact of uncertainties in workmanship and operations in the final energy performance of buildings.

Most of the studies discussed in the next section take the variation in input parameters as a normal distribution. These variations when seen practically do not necessary apply. E.g. actual measurements of accumulated electricity use in the UK (Carbon Trust, 2011) show a non-normal distribution. For that reason, in this paper, probability distributions that are more representative have been used. They represent more closely what seen in reality. This point will be further developed in later sections.

Existing studies on uncertainty in building energy design

There have been many studies in the last two decades vis-à-vis uncertainties influencing the results of BATs. However, the studies are mainly theoretical and have not been applied in real world problems. Pettersen's work is one of the first studies that looked at the effects of climate variability, building characteristics and occupants (Pettersen, 1994). Using a statistical simulation method based on Monte Carlo Analysis (MCA), Pettersen studies the variation of energy use in dwellings, which was about 15%.

There is little literature showing the impact of uncertainties in specific inputs. De Wit studies the effect of uncertainty as well as relative importance of non-linear effects and parameter interactions on thermal comfort, using factorial sampling (de Wit, 1997) (de Wit & Augenbroe, 2002). He also explores effect of assumptions in measurement and simplification in calculations. Domínguez-Munoz studies the impact of uncertainties on the peak-cooling loads using MCA with a global sensitivity analysis to identify the most important uncertainties (Domínguez-Munoz, et al., 2010).

Hopfe et al. have also worked on uncertainty and sensitivity analysis for thermal comfort prediction to help in design decision making and optimisation (Hopfe, et al., 2007). Another paper written by Hopfe and Hensen (Hopfe & Hensen, 2011), covers the implication of uncertainties on energy consumption and thermal comfort using a theoretical case study and studying various building performance parameters using as inputs physical, design based, and scenario variables with their standard deviation.

Several works of MacDonald have focused on quantifications and application of uncertainty on the predictions of demand using building simulation software (MacDonald, et al., 1999), (Macdonald & Strachan, 2001), (MacDonald, 2002).His thesis (MacDonald, 2002) shows two ways of achieving this: The first way altered the input variables, requiring multiple simulations of systematically altered models and the subsequent analysis of the changes, with differential, factorial and Monte Carlo sampling; The second way altered the algorithm of BAT to include uncertainty at all computational stages. Applying these changes, the predicted uncertainty in thermo-physical properties, casual heat gains and infiltration rates was quantified and was compared with MCA and differential analysis. Further, the issue of non-convergence building simulations was discussed (MacDonald & Clarke, 2007). The non-convergence was caused by introduction of new uncertainty terms that were uncorrelated to existing terms.

In other recent works, Wang examines uncertainties in energy consumption due to annual weather variation and building operations using MCA (Wang, et al., 2012). Eisenhower enlarged uncertainty and sensitivity analysis to take into account the influence of 1000+ parameters (Eisenhower, et al., n.d.).

Uncertainties in India Context

The uncertainties in building input parameters are particularly relevant in the Indian context because of the techniques of construction used. Indian standards, codes and practices for construction allow significant tolerances and deviations in the fabric (IS: 2212: 2005 (BIS, 1991)), (IS4021: 1995 (BIS, 1995)), (IS: 4913-1968 (BIS, 2001)), (IS: 1948: 1961 (BIS, 2006)). General construction practice shows that most of the construction procedures are not consistent. From mixing of concrete by rough estimation to fabrication of wood framed doors and windows, all the work is done on-site. The quality is mainly dependent on the skills of the professionals. The doors and windows, constructed on site have gaps created at the time of installation which are filled with plaster (IS: 4913-1968 (BIS, 2001)) (IS: 3935: 1966 (BIS, 1986)). This technique compromises the U-value of the construction and airtightness and it might lead to thermal bridging because of the improper sealing and frame effects.

The bricks used for construction also have variation in their properties due to the variation in the composition of clay used and non-consistency of the firing process (Sarangapani, Reddy, & Jagadish, 2002). Small ducts for building services (plumbing pipes and electric conduits) are also embedded in the walls (SP20 (BIS, 1991)), (IS: 2212: 2005 (BIS, 1991)). This reduces the wall's thermal effective thickness, affecting the overall U-value. These inconsistencies in the fabric can create variation in the actual energy use. We show here a method to quantify this effect. We think it is a powerful tool for policymakers, as it will enable them to understand the fruitless and somewhat detrimental impact of stringent energy policies on an un-prepared industry. In other words the building sector, at present, is not prepared for incorporating energy policies unless the functioning of the whole sector is modified. The building components used should be quality controlled, ensuring consistency in performance then only the energy polices can be implemented. Such recommendations are incorporated in ECBC, e.g. supply-chain improvements to ensure availability of certified products, but are not exercised in practice.

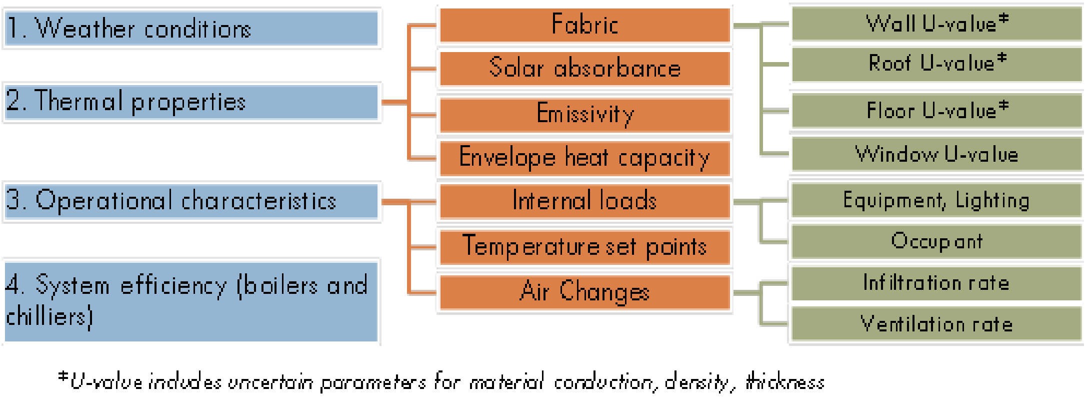


Figure 1 Uncertanity Parameters included in existing studies

In order to estimate the overall effect, uncertainties due to variation in inputs, discussed earlier, have to be combined with the impact of construction procedures in India on the building fabric. Studies exploring the latter issue were not found. Based on past studies (Heo, et al., 2012), (de Wilde & Tian, 2009), (Hopfe, et al., 2007), (MacDonald, 2002), (Wang, et al., 2012), (Pettersen, 1994) on uncertainty (Figure 1) and assuming the uncertainties because of local factors, uncertainties in various parameters are estimated. A more accurate finding of the distributions is suggested for further work. For this paper, we have used generic distributions that could be changed for each region to obtain more accurate results.

In this paper, a methodology for uncertainties related to thermal properties, temperature set points, internal loads and ventilation is presented. Weather, system efficiencies and other operation parameters have not been considered in this study, but the method can be extrapolated to include these too.

METHODOLOGY

Uncertainty propagation, sensitivity analysis (SA) and uncertainty analysis (UA) has been carried out in this paper in the following manner (*It has been assumed in this study that the input variables are not dependent*):

1. A baseline building with fabric based on ECBC specifications was created as refernce point.
2. Based on existing studies, six major uncertainty factors were selected and the calculations of their variability with probabilistic distributions defined.[1]
3. The deviation in conditioning loads and occupant comfort in relation to the input variables was explored. Random MCA sampling is used for input variables based on their determined probability distributions. Those samples are used for multiple EnergyPlus runs for Propogation of uncertainty.
4. Multiple Linear Regression (MLR) is done to asess the sensitivity of variables - sensitivity analysis (SA).
5. A mean and peak variation for each output is calculated to assess the uncertainty - uncertainty analysis (UA).

[1] It has to be calculated as there was no data found that could provide with the variations of these factors.

SIMULATION

Building Plan

The reference building is a three story residential building in New Delhi based on normal practice. The floor area is 75 m^2 (total built up area of 225 m^2). The floor-to-floor height is 3 meters. The building has longer axis along E-W direction. The Living (4.275m*4.8m – with toilet)/Dining (2.915m*2.8m) room is in North and the bedrooms are located on in SE (3.915m*4.21m) and SW (3.235m*4.21m – with toilet) corner; the kitchen faces West (2.8m*1.885m). Each room is taken as a separate zone.

Construction and operation

The building has a mixed mode running system with natural ventilation happening between heating and cooling setpoints. Table 1 below shows the input parameters for the initial base case.

Table 1 Table showing the input parameters taken for the baseline building model

Criteria	Remarks
Structure	RCC and brick infill panel walls
Walls	0.44 W/m2K ; Insulated brick cavity walls
Windows	3.3 W/m2K; Openable, and air filled clear double glazed (6-12-6)
Roofs	0.40 W/m2K; Insulation covered RCC slabs
Setpoints	Heating -19°C; Cooling - 24°C

Room type	Occupancy schedule		Internal gains
Bedroom	Weekdays	2200-0600	2 people, 1 TV, 1 tube light, 1 fan
	Weekends	2200-0600; 1400-1600	
Kitchen	Daily	0600-0800; 1200-1400; 1900-2100	1 person, 1 tube light, 1 fan, 1frige
Living/dining room	Weekdays	0600-1000	4 people, 1 TV, 8 tube lights, 4 fans
	Weekends	0600-0200; 1600-2200	

Outputs considered

Two outputs were obtained from the simulations: (1) the total heating and cooling energy use; and (2) the number of non-comfortable hours of the occupied spaces. The standard ASHRAE 55-2004 Predicted Mean Vote (PMV) was used to define non-comfortable hours (integrated in EnergyPlus).

Variable inputs and their distributions

As described earlier, based on existing research, the uncertain factors taken are fabric thermal properties, temperature set points, and ventilation. The section below describes the input variables and Table 2 shows the base case, upper and lower values distributions selected and their variation graphs.

Internal loads

Internal loads are one of the most significant aspects governing the building performance. Internal loads cannot be negative, thus, a normal distribution is not ideal to represent the variation in internal loads. In previous studies (Schnieders & Hermelink, 2006) internal loads have been assumed to vary in a symmetric distribution. However, in actual measurements done on accumulated electricity use in the UK (Carbon Trust, 2011) it has been seen that the electricity use has been an asymmetric distribution.

Infiltration rate

Infiltration is primarily due to construction defects, gaps and cracks. Onsite fabrication of windows and high tolerances in construction of fenestration increase infiltration drastically.

Temperature set points

Set points depend on personal preferences. Variation in heating and cooling set points is assumed to follow a normal distribution as these variables are far from zero, therefore could be assume symmetric. During sampling, if the heating set point is less than 2 degrees below the cooling set point, the sample is rejected and another one calculated as this is considered the width of comfort (ASHRAE, 2009).

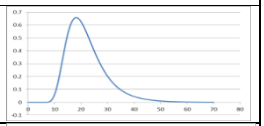
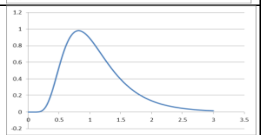
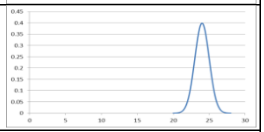
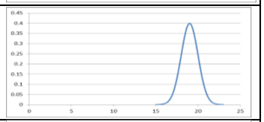
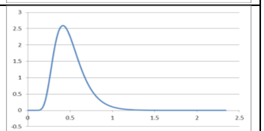
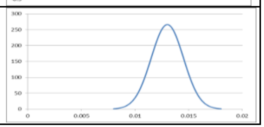
Wall U-value

Wall U-Value has a large impact on energy calculations. Standard deviation in U-values because of measurement techniques is 5 % (MacDonald, 2002). Moreover, due to construction techniques, detailing and material manufacturing processes, the variation is more. It is more likely that errors in manufacturing processes and workmanship lead to a larger U-Value (lower quality).

Window U-value

The in-situ construction of windows will affect the overall U-Values. The variation in the overall U-Values is mimicked by changing in thickness of the cavity as we consider it is the parameter of the window more likely to vary in a production process with poor quality control.

Table 2 Uncertain parameters chosen and their distributions

Parameter	**Element changed**	**Units**	**Base**	**LB**	**UB**	**Distribution Name**	**Distribution details**	**Graph**
Internal Loads	Equipment Loads	W/m^2	20	10	50	Scaled inverse chi-squared	μ = 20 ; τ^2 = 2	
Infiltration Rate	Space Infiltration Design Flow Rate	Ach/h	0.75	0.25	2	Log Normal Distribution	σ= 0.45; μ=0	
Cooling Set points	Thermostat	°C	24	22	26	normal	μ= 24; σ^2= 1	
Heating Set points	Thermostat	°C	19	17	21	normal	μ= 19; σ^2= 1	
Wall U-Value	Insulation Cond.	W/mK	0.03	0.02	0.11	inverse gaussian	μ= 0.5 ; λ= 4	
Window U-Value	Air Gap	mm	0.013	0.010	0.016	normal	λ= 0.013; σ^2=0.0015	

LB=lower boundry; UB=upper boundary; μ=mean, σ^2=standard deviation; λ=shape parameter; ν=degrees of freedom and τ^2=scale parameter

SIMULATION RESULTS ANALYSIS

Based on the values ranges and the PDFs, values between the upper and lower bounds are selected by random monte-carlo sampling for multiple simulation runs. Results of all 3427-simulation runs are analysed to propagate the uncertainty and to perform a SA and UA.

Uncertainty propagation

The histograms in Figure 2 show variation in heating and cooling energy use and non-comfortable hours (minimum, average and maximum of all zones). Being a cooling dominated climate the cooling energy use is in GJ and heating energy use is in MJ. The cooling energy use in the building varies between 150 GJ and 385 GJ with the peak frequency at 225 GJ. Heating energy use shows a very large variation with values ranging from zero to 17GJ. The peak frequency is at 100 MJ of energy with the average use of 446 MJ. The graph is presented in logarithmic scale. For the non-comfortable hours the values vary from 0 to 2180, 0 to 3110 and 0 to 4960 for minimum, average and maximum for all the rooms respectively.

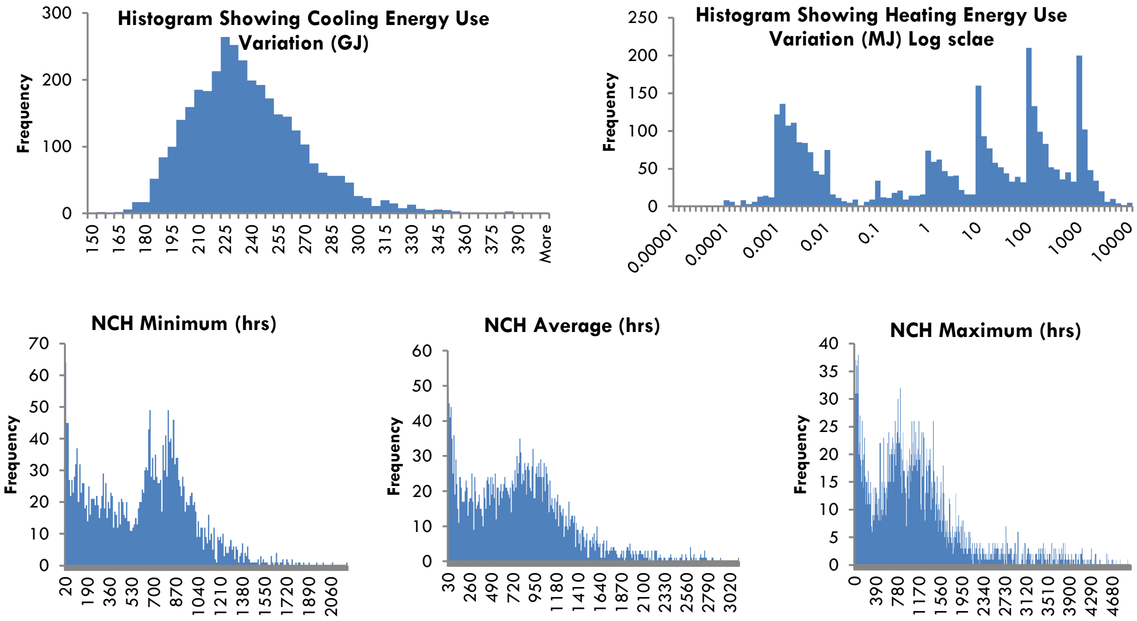


Figure 2 Histograms showing spread of output results

Sensitivity Analysis (SA)

Sensitivity of each input, for the outputs is gauged through regression. The analysis is similar to one in (Blight & Coley, 2013). Table 3 shows adjusted R Square value and Significance F for regression.

Table 3 Results of regression analysis showing adjuster R square value and significance F

Output Variable	adjusted R square	Significance F	Remarks
Cooling Energy Use	0.9869	0	Regression model fits the outputs very well. Coefficient values are significant.
Heating Energy Use	0.5460	0	There are more factors which affect the output. Coefficient values are significant
Non Comfortable Hours Min	0.8635	0	Regression model fits the outputs very well. Coefficient values are significant.
Non Comfortable Hours Avg	0.8183	0	Regression model fits the outputs very well. Coefficient values are significant.
Non Comfortable Hours Max	0.7213	0	There are some factors more affecting the output. Coefficient values are significant

It can be seen that adjusted R square values are high (except heating energy use) showing high accuracy of the data. Significance F value is 0. This shows that the variables are still important and relevant enough and that the results are not by chance. The regression analysis is done at 95% confidence interval and P-value <0.05 in Table 4 shows that those input variables are significant for the output. Green means significant and red means insignificant.

Table 4 P-value (significance) of inputs for the different outputs

	Insulation Conductivity	Window Air Gap	Internal Loads	Cooling Set points	Heating Set points	Infilteration Rate
Cooling Energy	0	0.79	0	0	0.13	0
Heating Energy	0.00003	0.48	0.000001	0.0001	0	0
NCH Min	0.0003	0.59	0	0	0.34	0
NCH Avg	0.023	0.29	0	0	0.29	0
NCH Max	0.23	0.21	0	0	0.33	0

Residuals for each output also show randomness and equal distribution about the x-axis thus showing homogeneity and linearity and verifying the credibility of the regression.

The standardised coefficients are found by dividing the 'distance from the mean' by the standard deviation of each variable, and can be used to directly compare the relative contributions from independent factors. The taller the bar, more influential is the input on the output. Positive means a direct relation between the change and vice-versa.

The most influential variables for cooling energy use are internal loads and cooling set points with infiltration and wall U-value next. Window air gap does not have any big impact on the output but does change is a little. Similarly, for heating energy use infiltration and heating set points are factors that are more dominant. For the NCH hours Infiltration, internal loads and cooling set point affect the outputs the most.

It can be seen that occupant behaviour is the most important aspect as in most cases; they determine the internal loads and cooling set points. A conservative approach in estimating the internal loads can be quite detrimental when calculating building's cooling energy needs and comfort. Infiltration and U-value of the fabric also show that construction and proper airtightness is required.

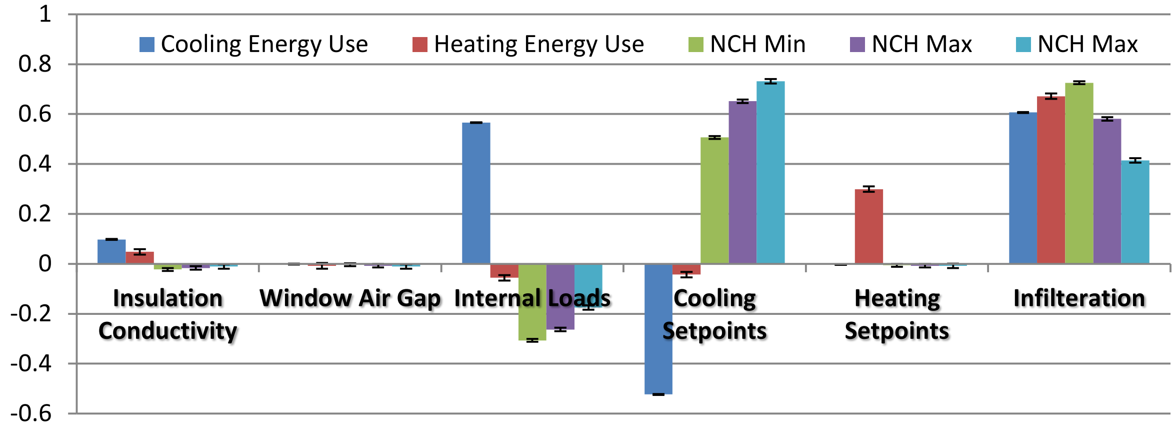


Figure 3 Standardized regression coefficient comparing the relative influence of the explanatory variables on the dependent variables

Uncertainty Analysis

The values in all outputs show substantial variation. Table 5 below shows the upper value, lower value, mean value, and standard deviation of the various outputs.

Table 5 Spread of the outputs because of variations in the input values

Outputs	Maximum Value	Minimum Value	Mean	Std. Dev.
Cooling Energy (GJ)	384.97	152.36	234.94	31.76 (13%)
Heating Energy (MJ)	17305.56	0.00	441.30	1150.85 (260%)
NCH Min (hrs.)	2177.75	0.00	495.17	411.92 (83%)
NCH Avg (hrs.)	3107.14	0.00	711.02	454.58 (63%)
NCH Max (hrs.)	4955.50	0.00	1108.89	888.76 (80%)

It can be seen from the results that the variation is very big and outputs have very high percentage of uncertainty. Through the results, it can be seen that occupant behaviour is the most important aspect as in most cases; the occupants determine the internal loads and cooling set points. A conservative approach in estimating the internal loads can be quite detrimental in assuming building's cooling energy needs. Infiltration and U-value of the fabric also show that construction and proper airtightness is also required.

CONCLUSION

Through this study, it has been shown that there could be a significant variation in the simulation result output because of the variation in the inputs. Cooling energy use because of occupant usage and construction quality alone could produce variations over the mean of about 13% with the variation in maximum and minimum values of more than 150%. Similarly, non-comfortable hours in the year could have a variation of whole year comfortable to more than half a year uncomfortable. While, the sensitivity analysis it is seen that the most influential variables in regarding the increase the cooling loads and decrease in comfort are internal gains and cooling set points, both factors primarily governed by occupants. Infiltration and U-value of the walls are similar on importance; both are primarily governed by quality of construction. Therefore, owing to these persistent uncertainties, simulation results should be taken in a more probabilistic manner to ensure that the risk associated with the uncertainties in the inputs is also calculated when making the assessment.

Another important issue that needs to be addressed when performing uncertainty analysis is that the type probability distribution of input variables should be based on realistic factors and measured data. The use of normal distributions might not represent the actual variation in some cases as it has been shown here. Fail to use the right distribution could render the methodology misleading.

It is of prime importance that the uncertainty on input variables is considered when performing energy assessment. Obtaining stochastic results encourage constructor and designers to take the adequate measurements to minimise this variation when it has a large impact in the final energy use of the building. This has even more importance in buildings in which low-demands are the aim.

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G-SEED : The Revised Korean Green Building Certification System

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ABSTRACT

The study introduces G-SEED (Green Standard for Energy and Environmental Design), with particular reference to the importance of the government's role in the dissemination and diffusion of Green Architecture through the certification system, incentive schemes and certification records. In addition, the need for improvement of the current environmental performance has been discussed through green building diffusion in Korea, by introducing the revised G-SEED and further directions for improvement.

1. INTRODUCTION

Background and Purpose of Research

The Korean G-SEED (Green Standard for Energy and Environmental Design) was initiated in 2002 for efficient building energy consumption and reduction of greenhouse gas. G-SEED is quite different from LEED (US) and BREEAM (UK) in terms of government-developed certification systems. The Korean government fulfilled critical policies as an obligation of the public building certification for diffusion, expansion and dissemination of green architecture, introduction of different incentives to induce the private sector's building certification in short-term plans. Also, in the private sector there was different voluntary participation in this certification process for business and value improvement in the building industry through reduction of energy consumption and promotion of a healthy indoor environment. Thus, the green building certification system in Korea was successfully developed within a decade thanks to strong government policies and positive support from the private sector. Therefore, both the public and private sectors have contributed to the environmental performance improvement and energy saving. Particularly given the poor political and industrial infrastructure and the scant realization of the importance of green architecture in the private sector, Korea's successful rapid implementation of a green building policy might provide a good model for developing countries planning to introduce green architecture.

Scope and Method of the Research

The purpose of this research is to examine the changes in private building construction records according to the certification incentive system in Korea and the expansion of certification records through obligation of certification. In addition, the research aims to examine the changes in factors such as building energy reduction and environmental performance improvement within the green building certification-assessment standards. Finally, we will analyze the development of Korea's green building certification system to analyze what made the certification system successful.

2. GREEN BUILDING CERTIFICATION SYSTEM IN KOREA

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The research for green building certification in Korea began in 1996, promoted by the Ministry of Construction and Transportation. First the certification was applied to apartment buildings but eventually it was expanded to education facilities, offices, and currently all buildings are included in its certification scope and from 2013 all buildings 3,000㎡ or over were obliged to be certified. In particular, the ministries established the Green Architecture Support Act to legally implement the policies such as economic-institutional support for green architecture, establishment of information system and education of relevant professionals, etc.

Operating Body and Certification Procedure

The operating bodies of the green building certification system are classified into management organization and certification organization. The management decides and establishes the diverse economic and institutional incentives as certification assessment standard, certification procedure, designation of entity for certification, inspection of certification records, etc. and the initial management organization was the Ministry of Land, Infrastructure and Transportation and the Ministry of Environment, which alternately managed with terms of 2 years.

Green Building Certification Records

In the green building certification records, the standard for apartment building was established in 2002 and in 2006 the certification records were increased to 142 cases. In addition, the office buildings standard was prepared in 2003 and in 2010 the certification records were increased to 110 cases. Meanwhile, the education facilities standard was prepared in 2005, and in 2007 the records increased to 120 cases. For other buildings, the standard generally was established in 2010 and in 2013 the records increased to 100 cases.

Related Regulations

Green Architecture Support Act. The Korean Government established and enforced the Green Architecture Support Act in February 2013, aiming to reduce greenhouse production by 26.9% until 2020 through a general and systematic green architecture promotion and progress plan considering that the building industry in Korea is producing 1/4 of all greenhouse gas production.

Local Government Ordinances related to Green Architecture. The City of Seoul established the Seoul City Green Architecture Support Ordinance in January 2014 according to the enforcement of Green Architecture Support Act in February 2013, to expand green architecture and reduce the greenhouse gas generated by buildings.

3. INCENTIVE FOR CERTIFICATION

The economic-institutional support consisted of exemption of acquisition-registration tax, property tax, relaxation of architecture regulation, environmental improvement charges, additional charges for design services and obligation of public buildings.

Incentives related to acquisition-registration tax. The period in which the acquisition-registration taxes were reduced over 5~15% for green building certified buildings to promote green building was May 2009.

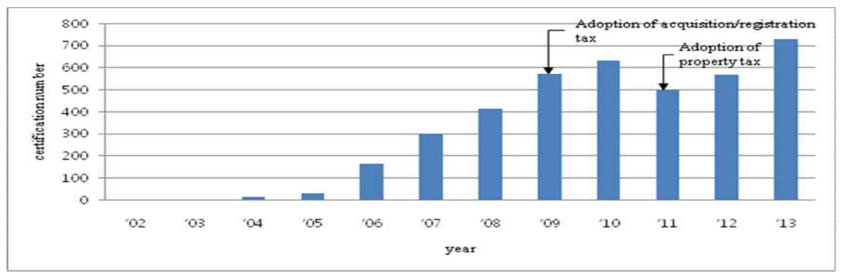

Figure 1 Current status of certification cases (March, 2014)

The number of certified buildings in 2010 increased to 570, which is 156 more than the 414 certified buildings in 2008. Also, the property tax the exemption period is December 2011, it was found that compared to 500 cases in 2011, certification number is increased by 567 in 2012.

Additional Price Incentive. The incentive system for apartment buildings was revised in March 2005 to add 3% of the basic construction cost when the green building certification was acquired according to the regulations of the Calculation of Parcel Price (Article 13-2) for Housing price ceiling system[1] applied to apartment buildings. Therefore the certification records of apartment buildings rapidly increased, from 33 cases in 2005 to 163 cases in 2006

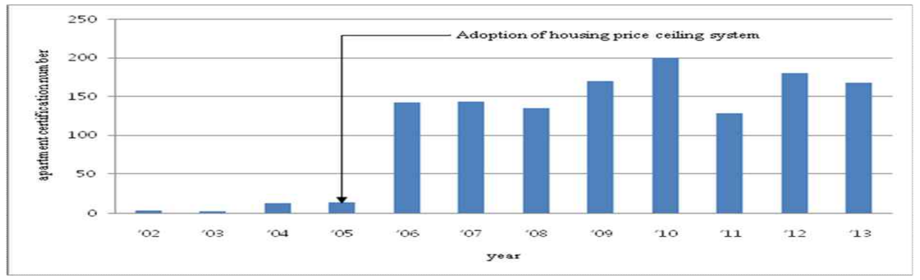

Figure 2 Current status of certification of apartment buildings (March, 2014)

Obligation of public buildings and Green Building certification records. The regulation on the obligation of green building on public buildings was revised in March 2010 according to the energy usage rationalization guideline. There were 64 public buildings with certification, 19 more than in 2009. Furthermore, in December 2011 the standard was revised to apply at least Excellent level for public office buildings.

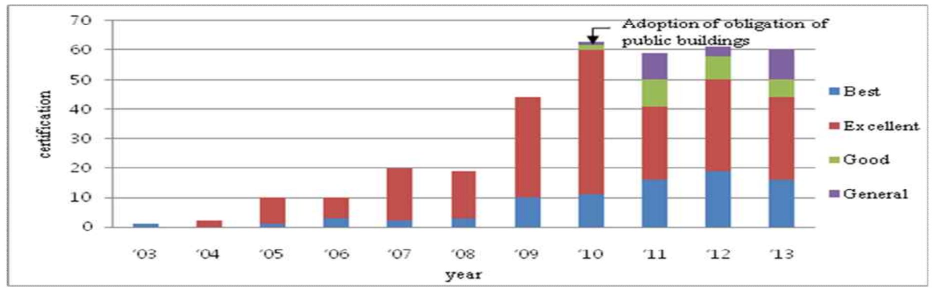

Figure 3 Current status of certification of public office building/facilities (March, 2014)

4. CHANGE OF BUILDING ENERGY-REDUCTION AND ENVIRONMENTAL IMPROVEMENT FACTORS IN G-SEED

ENERGY-SAVING EFFECT OF THE BUILDING

Building Energy-saving. The building energy-saving sector was assessed as an EPI item from 2002 to assess the energy consumption. There were only 12 energy consumption points among all other items of energy sector, but in 2010 the system was modified by applying the weighting, and therefore it was increased to 15 points. Thus, the importance of the energy-saving sector (energy consumption) is increasing daily.

Obligation of use of Renewable Energy: In 2002, renewable energy such as sunlight, bio-energy, wind power to reduce the use of fossil fuel and increase renewable energy facilities was only applied to the apartment buildings and the hot water supply, but from 2003 it was modified to produce 1~5% of the total electric design load, air-conditioning and heating by renewable energy facilities.

[1] Parcel Price Ceiling System: System which designates the parcel price of the house calculated based on the site price, construction costs and the proper rate of constructor's income, which limits the price according to this calculation (Ref: Doosan Encyclopedia)

Table 1. Assessment standards of Energy-saving sector

Classification	Assessment standard
Energy consumption (2002)	Energy consumption assessment according to Energy Performance Index (EPI) points. Y = 12 × (EPIpts-60) ÷ 25
Energy consumption (2003)	Energy consumption assessment according to Energy Performance Index (EPI) points. Y = 15 × (EPIpts-60) ÷ 25
Energy efficiency improvement (2010)	Applied as energy performance index review

Improvement of Ventilation Performance

Material and Resources. The carbon emission of the material is an assessment item that was adopted in 2010 to assess the inherent carbon emission assessment and indication of the material information for the materials and resources used in the construction, and products that acquired the carbon certification were classified into 1~5 types. In 2013, the assessment was classified/divided into apartments and other type of buildings. Significantly, the greenhouse gases emission was indicated in the product for customers' information to contribute to the low-carbon consumption culture, and it is estimated that these carbon-related items will increase further.

Water resources. Rainwater reduction measures were adopted to reduce flood and maintain soil ecosystem in urban area in case of localized heavy rain. The assessment standard in 2002 was a 15~30% permeable paving ratio to reduce efflux of rain water by applying permeable paving, but the 2010 standard was modified to the ratio of rain water treatment facility installation compared to connected area within the total plottage to induce rainwater into the treatment facility. This means reducing efflux of rainwater to the plottage by inducing it to treatment (rainwater efflux reduction) facilities.

Ecological environment. The ecological area ratio is an item to induce the underlying resolution of the urban ecosystem through quantitative assessment of ecological function of the land (soil circulation, rain water circulation, air and climate control, habitat function, etc.) introduced in 2010 to assess by classifying the space type of the land and multiplying it by the weighting of each space type and comparing it with the plottage ratio.

Indoor ventilation. The natural ventilation was assessed in terms of availability for users, with an open-able windows area for each use to provide proper fresh external air, but currently it is assessed to procure natural ventilation by installing additional ventilation equipment for a complementary ventilation system.

Table 2. Natural ventilation performance assessment standard

Classification	Assessment standard
Natural ventilation (2002)	10~15% open-able windows area
Natural ventilation (2013)	2nd degree+natural and mechanical ventilation equipment composes 1 system, and when necessary one component can function in a mutual-complementary manner = combined ventilation system, installed.

5. CASE STUDY BUILDINGS

S Chemical BLDG. The S Chemical BLGD is located in Gyeonggi-do. The total architectural area of the building is 47,541.88㎡, with 5 basement floors and 9 floors above ground. The building acquired the Best G-SEED certification level and LEED (Platinum) certifications. The main application parts are: energy saving sector (energy performance index (EPI) 96 points), renewable energy (installed sunlight and geothermal heat pump system), BIVP installation, ecological material, rainwater and graywater, permeable paving rainwater load reduction plan, etc. In addition, using the temperature difference between the upper and lower atrium, an air control system, the S Chemical BLDG was planning to reduce the air-conditioning load and natural ventilation.

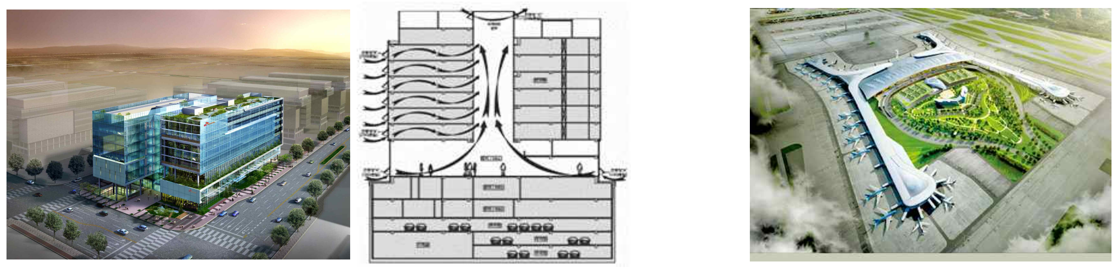

Figure 4 (a)Aerial view-Layout and main section of S Chemical BLDG. (b)Aerial view of New Terminal of International Airport

New Terminal of International Airport. New Terminal of International Airport project is in progress, with the total architectural area of the building as 384,000㎡, including 2 basement floors and 5 floors above ground. The building is estimated to acquire the Best G-SEED certification level. The main application parts are: considering energy saving sector according to energy performance index (EPI), application of carbon emission material, renewable energy (installed sunlight (BIPV) and geothermal heat), and ecological sector of interior garden and outdoor garden, etc. In addition, New Terminal of International Airport is designed to take advantage of the flow of outside air into the thermal tunnel, to improve the energy savings.

The FKI Building. The FKI building is located in Seoul. The total architectural area of the building is 168,629㎡, with 6 basement floors and 50 floors above ground. The building acquired the Best G-SEED certification level. The main application parts are: energy saving sector (energy performance index (EPI) 80 points), renewable energy (installed sunlight and geothermal heat), and ecological sector of rooftop greening, roadside plantation and bio-top, etc. In addition, The FKI building was planned, which will include solar panels on the roof and elevation to maximize the use of solar power. (The production of 4% electricity to 728,971 kw solar power generation amount)

Figure 5 (a) Perspective and elevation detail view of The FKI Building (b) Aerial view of W New City, Apartment building.

W New City. The apartment complex of W New city is located in Seoul. The building consists of 2 basement floors and 11~19 floors above ground for 1493 households. In the green building certification the building is implementing the development for acquisition of G-SEED excellent level certification. The main applications are energy-saving sector (application of 1st degree of energy efficiency), new regeneration energy (sunlight and geothermal heat), and in the ecological part an artificial ground green belt and green wall curtain were applied, while in the interior a mechanical-device for excellent ventilation function was featured. In addition, the W New City apartment complex was planned to introduce a geothermal heat pump system, which will be responsible for generating the equivalent of 3.49% of the total energy.

6. DISCUSSION

The green building certification system in Korea, which was adopted in 2002, had been applied to over 4000 cases of certification records in a short period of about 10 years, contributing to the spread of green architecture in Korea. By increasing the energy efficiency it also played an important role in the reduction of greenhouse gases. This was thanks to strong government support to respond to the private sector's demand. The successful case studies shall be an exemplary reference for further green architecture introduction, diffusion and dissemination for other countries.

The Green architecture support act, which was established in 2013, consolidated all the scattered green construction related regulations and standards and encapsulates the generalized and comprehensive green building policy and promotion plan. By enforcing diverse and effective ecological and energy-saving green architecture dissemination policies such as the establishment of a certification system, establishment and disclosure of an information system, designation of a professional organization, education and training of professional operators, etc., it became a strong legal basis for the dissemination and expansion of green architecture by the government and local governments.

Green architecture suffered various difficulties in its initial phase of voluntary diffusion due to increased investment costs, though it assured the improvement of environmental performance of buildings. These were surmounted through diverse economic and institutional incentives provided by the government, and certifications increased explosively after the enforcement of the certification incentives. The public sector led the private sector by requiring certification and established a paradigm in which long-term innovative design took precedence over short-term economic profit.

The building industry in Korea also developed rapidly. As skyscrapers and diverse complex buildings increased, issues such as global warming showed the problematic nature of the curtain wall method, leading to a general change and improvement in the construction industry. Korea's green building assessment and certification system, initiated in 2000 and implemented in 2002, have improved and developed assessment standards for the most optimal assesssment, and led the construction industry by responding to the demands of the private sector through measures such as departmentalization of certification levels, diversification of buildings for certification, etc.

The development of professional bodies to support the government policy is critical to the success of the certification system. The green building certification is based on fairness, objectivity, consistency, and the subsidiary roles such as education and consulting for the constructor, designer and operators also guarantee the greater effectiveness of this certification system. In addition, its role as a medium that delivers the industry's demands to the government and reflects them in policies is also a critical function of the certification institutes. Also, its role as a professional certification institute that performs education of professionals and accumulation of relevant technologies is a critical factor affecting the general sector of certification system. If the certification body is not reliable, the entire certification system loses credit and fails.

7. CONCLUSION

As mentioned previously, for the dissemination and diffusion of green buildings, a certification system based on relevant regulations is essential, and therefore a fair and professional certification institute must be developed. By reflecting these features of a certification body the institute needs a strategy to survive within a system of autonomic competition. Furthermore, though the obligation of public areas it must take an initiating role and grant diverse and effective incentives to the private sector to promote the rapid proliferation of the certification system. To continue and maintain this, the certification system must be steadily improved and developed to provide actual benefits to prevent dismissals. The greening of architecture that results will have great results, including the reduction of greenhouse gases, saving of resources and efficiency of energy consumption, which are critical problems in architecture from an economic-environmental point of view, as well as improving the residential environment, and thus promote global sustainability.

Meanwhile, from 726 cases certified as green architecture in 2013 by G-SEED, only 118 cases were certified by the Korea Research Institute of Eco-Environmental Architecture (KRIEA), which corresponds to 16.3% of the total records and 2nd place in the entire certification records scope.

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4. Verify the Ministry of Land, Infrastructure and Transport web page (www.milit.go.kr)

Developing Free-running Prototypes for different Climates of Chile

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ABSTRACT

This paper presents results from thermal simulations conducted for a terrace house in Santiago (33˚S). Previous findings from field studies concluded that despite the use of polluting space heaters social housing households were unable to heat their homes to an adequate level of warmth, being exposed to noxious pollutant gases and also forced to live in fuel poverty. The studies presented here investigate whether adequate thermal comfort conditions can be provided in free-running buildings, i.e. neither heated nor cooled mechanically, within the economic limitations posed by social housing standards. Results from thermal simulations have evidenced that, through passive heating and cooling design techniques, thermal comfort can be achieved at low costs without any additional energy inputs all year-round. These results will be further used to develop a modular housing prototype for the varied climates of Chile.

INTRODUCTION

Over the last five decades, the development of social housing policies has led most Chilean cities to a scenario of social and environmental exclusion. Driven by a large housing shortage the proliferation of hundreds of thousands of apartment blocks spread around suburban areas created high poverty ghettos, characterised by low quality housing, raised levels of air pollution and degraded thermal environments. The combination of thermally inefficient housing stock and the use of fossil-fuels for space-heating have long been threatening public health and well-being in poor suburban areas. Although studies have revealed high levels of indoor air pollution attributed to the use of unvented space heaters low-income households have been unable to heat their homes to an adequate level of warmth (CENMA, 2011; Ruiz et al., 2010). Moreover, high fuel costs exacerbate vulnerability and forces inhabitants to live in fuel poverty.

With a deepening energy crisis and the prospect of fuel price increases looming large on the horizon, fuel poverty has become a progressively more urgent social issue in Chile. Although the negative impacts of thermally inefficient housing have been largely acknowledged, as well as their adverse effect on poverty, the supply of polluting fuels for residential space heating has remained unquestioned politically. This highlights the question as to whether polluting fossil-fuels are necessary to provide affordable warmth. Previous studies have proved that more thermally efficient housing could reduce space-heating demand without incurring significant extra capital costs (Bustamante et al., 2006; Méndez, 2008), but is it possible to do so under free-running conditions?

THERMAL SIMULATION STUDIES

In order to test whether thermal comfort can be provided without additional energy inputs, parametric simulations were carried out using as a case study a building in Santiago. The aims of this research is to investigate the thermal performance of housing and develop passive heating and cooling design techniques for different climates of Chile. The study here outlines a criteria to evaluate thermal comfort in residential buildings, as well as present results from a series of thermal simulation tests conducted to find the appropriate combination of passive designs to achieve thermal comfort at low costs. The results from this will be used to inform the design of a prefab modular prototype, *Prototype Zero*, proposed to test the research objectives through further thermal simulations for the cities of Antofagasta (23˚S) and Puerto Montt (41˚S). The final outcome of the project will be the design proposal of a net-zero apartment district located in inner-city Santiago.

The building case study was selected from a sample of buildings studied under the present research framework. This provides a reliable base case supported by monitored temperature results and field study observations. The selected scheme corresponds to a three storey intermediate terraced house with a total habitable floor area of $55m^2$, taken from *Olga Leiva* social housing development. **As shown in Figure 1**, since the house has a low level of exposure and the insulation of its exterior walls are below minimum standards, this is a U-value of 1.9 W/m^2K, the overall heat loss coefficient results to be significantly below an average detached house for the same location.

In order to evaluate the thermal performance of the house in relation to occupants' preferences, a thermal comfort index is proposed. This provides a weighted indicator of the effective thermal comfort contribution made by each design strategy as well as allowing comparisons to be drawn against final construction costs. **As shown in Equation 1**, the thermal comfort index expressed here as ΔT_c sums the hourly difference between resultant operative temperatures and monthly comfort temperatures estimated from an adaptive model of thermal comfort. In order to simplify results, the index is assumed to equal zero when temperatures are outside thermal comfort thresholds.

$$\Delta T_c = | T_{op} - T_c | \qquad \textbf{(1)}$$

Where : T_{op} = Operative temperature
T_c = Monthly comfort temperature

To keep track of the impact of each design parameter over final construction costs, a marginal cost index ΔMC was proposed. As shown in **Equation 2**, the index, which is the simple difference between initial construction costs and final construction costs of a given building when incurring any design modification, allowed thermal performance to be optimized against construction costs allocated by current housing programs. This was accomplished through a series of simulation tests conducted after the completion of the parametric studies, by further testing the sensitivity of the building to the combination of the lowest resulting comfort indexes. In order to find the appropriate combination of passive design techniques, the simulation results were computed using an analysis matrix, containing both, comfort and marginal costs indexes for each variant tested.

Figure 1. Building case study, plans and construction specifications

The criteria adopted for the cost-benefit analysis is based on subsidy schemes granted by social housing programs. According to government sources (MINVU, 2013), the total construction costs granted for the poorest income quintiles, corresponding to the first title of the *Integrated Housing Subsidy System*, varies from nearly 22,700 to 52,000 USD. Although for the purpose of this research it was decided to adopt the minimum cost, in order to allow further improvements to the performance of buildings, the budget scheme adopted considered the addition of a thermal conditioning subsidy which in total reaches up a budget of 27,000 USD.

$$\Delta MC = C_f - C_i \qquad \textbf{(2)}$$

Where : C_f = Final construction cost
C_i = Initial construction cost

ADAPTIVE THERMAL COMFORT

The criteria by which thermal performance was evaluated was based on the assumption that thermal comfort is not a commodity, but an imperative constituent of an individual's right to overcome poverty. Therefore is crucial to distinguish first the subtle threshold between the notion of thermal comfort and health, the former being a condition of mind associated with an individual's perception, and the latter being a basic biological need for human survival. Under these terms, thermal comfort is stated here as an adaptable necessity subject to buildings' inherent capacity to provide shelter from outdoors, whereas looking beyond human thermal regulation capacity, an adequate level of warmth or coolness is a minimum condition required for the maintenance of health. The assumption that space heating is required if any of these limits are exceeded has undermined the responsibility of housing authorities to provide adequate thermal environments, creating a burden for the income of poor households.

Field studies conducted under this research study, during the winter of 2011 in Santiago, evidenced that none of the above definitions were actually met in social housing. Findings drawn from interviews conducted in *Olga Leiva* and *El Estanque* housing developments, unveiled the paradox of the 'cure being worse than the disease' as occupants claimed that, despite raised levels of air pollution and space heating fuel costs during winter, estimated at an average around 40USD for a monthly heating load of 100kWh, above the 10% of the poorest quintile income average, the level of heat provided by common kerosene and gas space heaters was not sufficient to cover their thermal needs, where surprisingly in order to ensure health and safety many interviewees stated that they operated their houses under free-running conditions. So why are space heating fuels used at all?

The above observations were consistent with monitoring data and comfort survey results. Whereas building monitoring showed that indoor daily temperature averages around 14˚C, the outcomes of a survey conducted on a sample of 100 households showed that indoor temperature patterns tended to follow outdoor patterns, exhibiting mean comfort votes of 15.9˚C and 17.3˚C, in *Olga Leiva* and *El Estanque*, respectively (Felmer, 2014). The evidence suggests that a more open connection to the outdoors widens the scope of temperature ranges into which occupants express thermal satisfaction. Providing that people's health is ensured through limiting building temperature extremes, an adaptive approach to thermal comfort is advocated here through the integration of adaptive thermal controls aimed at reducing space-heating, and to providing thermal comfort all year-round.

$$Tn = 17.8 + 0.31\,Tm; \quad Tc = Tn \pm 3.0 \qquad \textbf{(3)}$$

Where : Tn = Neutral temperature
Tm = Mean monthly temperature
Tc = Comfort temperature

In order to widen the study across other seasons and climates, comfort temperature ranges were estimated from a database of field studies by de Dear & Brager (2001). The model adopted was developed over a linear regression obtained from the revision of 22,000 sets of raw data compiled around different climates world-wide. **As can be observed in Equation 3,** thermal comfort limits were taken as ± 3K from thermal neutralities estimated for each month. In order to parallel with studies in social housing, the algorithm was estimated for the same period (August; Tm= 9.8 ˚C), resulting in a lower limit of 17.8˚C, higher than the comfort votes showed above, the equivalent of a monthly heating load of 500kWh. Although this is low, fuel expenses are unaffordable for low income households.

OCCUPANCY HEAT GAINS

Heat gains from occupants and appliances were estimated from field study observations in *Olga Leiva*. Although there is no empirical research on the matter previous assumptions estimated an average daily heat load for standard residential buildings of around 5.0 W/m^2 (Hatt et al., 2012; Müller, 2003). Whereas, the average daily heat load adopted for the studies presented here was estimated at 7.0 W/m^2, by considering that 4.0 W/m^2 comes from occupants; 2.0 W/m^2 from appliances and 1.0 W/m^2 from lighting. This results in a total daily heat load of 9 kWh, resulting at a similar rate to previous studies conducted for social housing (Bustamante, 2009). The house was assumed to be occupied by four occupants, two adults and two children, considering continuous occupation by one member of the household, while one working adult and the children out for most of the day. In order to cover energy end-uses other than space heating, only electric efficient equipment was considered, obtaining lower energy consumption rates than an average household in Santiago.

INFILTRATION AND VENTILATION

Air infiltration rates were taken from recent empirical studies conducted to set a baseline for residential buildings. Previous simulation studies by Bustamante (2009) assumed a value of 1.0 ach as the maximum acceptable limit for thermal efficiency in social housing. However, recent evidence gathered from studies around different climates has proven that higher air tightness can be achieved with simple economic measures (Cortes & Ridley, 2012). Results from pressurization tests conducted to set a baseline standard by Figueroa et al. (2013), exhibited values ranging from 0.12 to 2.5 ach under normal pressure conditions, for both brick and timber constructions. The air change rate adopted here was then 1.2 ach, corresponding to the average value of the sample. Minimum fresh air supply rates were taken as 7.5 l/s per person for each room, when occupants were in at any given time (ASHRAE 62, 2005).

THERMAL PERFORMANCE

As can be observed in **Table 1**, preliminary simulation results showed that indoor temperatures were below thermal comfort limits during most of the heating season. This means the conjecture that current standards do not aim to target thermal comfort is borne out, as temperatures can drop significantly below mean comfort votes, or even further below recommended limits for healthy thermal environments. Results plotted for a typical winter's day, as shown in **Figure 2a**, were consistent with space heaters patterns of use, which was around an average of four hours a day between 6.00-10.00pm, and occasionally for a few hours during the morning. Thermal comfort conditions are only achieved during the hours around midday, and from there on temperatures steadily decrease reaching below 15˚C and reducing further to 10˚C during early mornings. On the other hand, results from a typical day in summer in **Figure 2b** showed that thermal comfort was only achieved in the living area, whereas in the bedroom resultant temperatures exceed the upper limit during most occupancy hours in the evening.

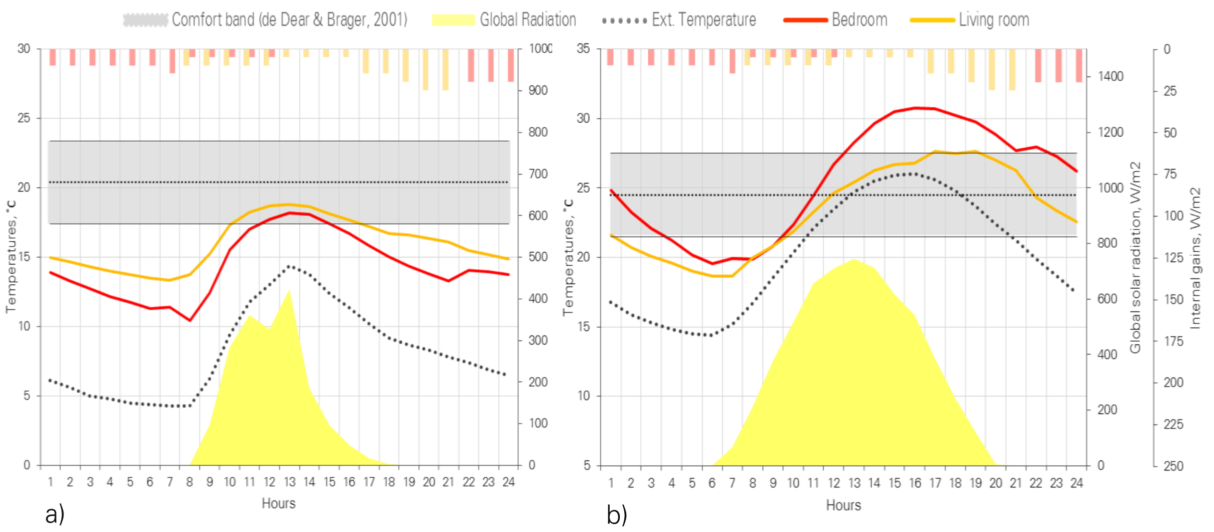

Figure 2. (a) Case study performance on a typical day in winter and (b) on a typical summer's day.

Table 1. Comfort Indices for the Building Case Study					
		ΔTc (Degree-hours)	ΔTc (%)	To min (˚C)	To avg. (˚C)
Winter	Bedroom	9,976	67	5.9	15.6
	Living room	8,943	71	7.9	15.6
Summer	Bedroom	3,228	49	36.3	26.3
	Living room	785	36	33.1	23.8

PARAMETRIC SIMULATION STUDIES

Since thermal comfort was not achieved, parametric simulations were carried out to test the influence of different design techniques. The aim was to select the parameters to be tested in further studies with a free-running prototype around the country's varied climates. Based on a review of previous studies by Bustamante (2009) and Müller (2003), the parametric variants proposed were based on four distinctive design principles: *heat loss control*, *passive solar design*, *thermal mass* and *natural ventilation*. These were considered as a conceptual basis to move from one climate to another. However the design approach adopted for each location might be subjected to the nature of each climatic problem, rooted in the interaction between occupants' thermal needs and outdoors. As the predominant problem found in Santiago was underheating and, as the sole choice, the use of polluting space heaters, the analyses were structured to provide thermal comfort during the heating season as a primary concern. The final result of each parametric variation can be consulted in **Table 2**, a brief description of the studies is given here below:

A. Airtightness: Following pressurization tests by Figueroa et al. (2013) infiltration rates of 0.12 and 2.5 ach were further tested, corresponding to the minimum and maximums values of the sample. Results from the case study evidenced a great sensitivity to slight variations in air change rates, improving significantly performance from the highest to the lowest values tested, reaching up to 5K during occupancy hours, and nearly to 2.5K average across the whole period assessed. The airtightness standard of the building proved to be crucial to allow sensitivity to any other design parameter, thus further analysis was carried out under 0.12 ach, advocated as an acceptable limit for thermal efficiency.

B. Insulation of External Walls: As previously discussed in relation to the low exposure levels of the house, the addition of insulation on external opaque elements exhibited no significant influence. Different insulation thicknesses were added on exterior walls, including further testing of alternatives, at 75mm (U=0.5 W/m^{2}K), and 100 mm (U=0.4 W/m^{2}K). Results exhibited no meaningful differences in both seasonal periods, suggesting that even lower resistances can be specified.

C. Interior Shutters: Despite reduced windows areas, this parameter showed to be decisive for providing thermal comfort during winter evenings. This can be explained by the ratio of glazing surfaces when compared with all exposed elements, and by the low resistances allowed for windows in current regulations. Two different alternatives were tested, one by replacing single glazed windows with double glazing (U=2.9 W/m^{2}K), and other by the incorporation of interior night shutters (U=0.7 W/m^{2}K), operated between 8.00pm-8.00am. The use of the shutters exhibited great efficiency, increasing temperatures by nearly 2K during evening hours, while being considerably cheaper than the double glazing alternative.

D. Window Size: In order to assess passive solar heating potential, different window sizes were performed. The windows of the case study were decreased to meet the minimum allowable size set by social housing standards, a corresponding net glazing area of 1.0 m^2, and increased up to 2.0m^2. The results showed that by simply facing windows towards the equator, incoming solar radiation can provide sufficient amounts of heat to increase indoor temperatures above thermal comfort limits, although higher levels of thermal mass would be required to stabilize indoor temperature fluctuations.

E. Thermal Mass of External Walls: Thermal mass was examined through different brick masonry constructions used in social housing. The exterior walls, built on lightweight timber construction, were performed with two different brick constructions, a ceramic perforated brick, and a clay solid brick, using the same insulation thickness. Results evidenced that thermal mass had a great potential to reduce high daily temperature fluctuations, contributing to stabilizing indoor temperatures during both seasons. The solid brick solution proved to be remarkably cost efficient, since being more economic than its alternative, exhibited a more robust performance, reducing peak indoor temperatures by nearly 5K, and even further up, to 10K on some unfavourable winter days.

In order to conduct the cost benefit analysis, each design variant tested was compared against final construction costs. In order to reduce the data inputted in the analysis matrix, comfort indices were estimated only from bedroom performance results over a sample week selected in winter. **As shown in Table 2**, the matrix allowed a first improved house, based on the combination of best results obtained across the studies to be set. Since this did not necessarily represent optimum performance, either in terms of thermal comfort or costs, further tests were carried out to investigate the influence of each variant under the combined effect of the different design parameters. The results from the second improved house initially proved that thermal comfort can be achieved within reasonable costs. However a final simulation was required to test whether acceptable thermal conditions can be provided during critical occupancy hours.

Table 2. Parametric Studies Results for a Winter Week

	Building Case study	B B1	C C1	D D1	E E1	∑ΔTc (Degree hours) 515	ΔMC (USD)
B	B2= 75mm insulation	**B2**	C1	D1	E1	488	529
	B3= 100mm insulation	**B3**	C1	D1	E1	462	849
C	C2= Double glazing	B1	**C2**	D1	E1	437	959
	C3= Interior shutter	B1	**C3**	D1	E1	380	363
D	D2= Net glazing area of 1.0 m²	B1	C1	**D2**	E1	508	-84
	D3= Net glazing area of 2.0 m²	B1	C1	**D3**	E1	532	1,080
E	E2= Ceramic perforated brick	B1	C1	D1	**E2**	401	2,102
	E3= Clay solid brick	B1	C1	D1	**E3**	318	1,786
	Improved House 1	**B3**	**C3**	**D2**	**E3**	**100**	**2,914**
B	B1= 50mm insulation	**B1**	C3	D2	E3	190	2,065
C	C1= Single glazing	B3	**C1**	D2	E3	234	2,551
D	D3= Net glazing area of 2.0 m²	B3	C3	**D3**	E3	40	4,078
E	E1= Lightweight timber construction	B3	C3	D2	**E1**	397	1,128
	Improved House 2	**B1**	**C3**	**D3**	**E3**	**53**	**3,229**

IMPROVED THERMAL PERFORMANCE

Results from parametric studies were used to develop a final design proposal. A last simulation was performed to adjust the thermal environment of each room to the hours of occupancy when the main problems were identified to occur. As shown in **Figure 3a**, based on the optimized case study obtained from the matrix, resultant indoor temperatures were found to be above thermal comfort almost all day round, ensuring occupants had the minimum conditions required to perform their daily activities and safeguard the maintenance of health. Moreover, the sensitivity of the house in relation to solar radiation

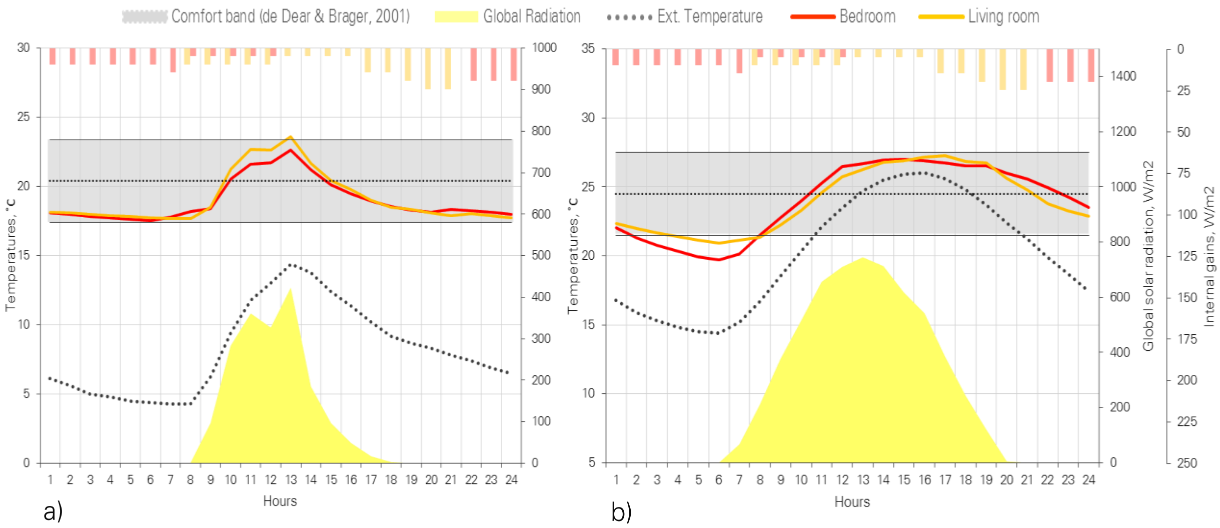

Figure 3 (a) Optimized building performance on a typical winter day and (b) on a typical summer day.

Table 3. Comfort Indices of the Improved House

		ΔTc (Degree- hours)	ΔTc (%)	To min (˚C)	To avg. (˚C)
Winter	Bedroom	205	8.1	14.8	21.0
	Living room	144	7.8	15.7	20.5
Summer	Bedroom	70	6.9	28.6	23.2
	Living room	64	5.2	28.7	22.3

offered the choice of achieving additional levels of warmth, providing appropriate thermal conditions to dispense with polluting space heaters.

Results from a typical day in summer proved that thermal comfort can be achieved through simple design techniques. The final building performed considered the addition of ventilation, either through windows opening or the operation of a fan, increasing air change rates by 12 ach and 15 ach during occupancy hours in the bedroom and living area, respectively. The use of exterior shutters was also considered, covering 25% of window areas. **As shown in Figure 3b**, the controls provided allowed indoor temperatures to achieve below thermal comfort limits for most part of the day, offering occupants the choice of adapting to changes in their thermal environment. Although in terms of fuel consumption this might not be relevant, overheating may lead to thermal stress and seriously affect the daily performance of different activities within the home.

Results from cost benefit analysis allowed to draw a final estimation of the construction costs required to meet the expected results. As can be observed on **Figure 4**, which comprised the replacement of standard aluminium windows with PVC; the incorporation of trickle vents; and the addition of 10mm of insulation on external walls (U=0.53 W/m^{2}K). As shown in **Table 3**, while resultant comfort indices where significantly reduced, the additional cost investment required was fully covered by the thermal conditioning subsidy reaching approximately 4,000 USD, the equivalent of 18% investment over the minimum construction costs allocated by the government.

CONCLUSIONS

The performance of the optimized house proved that adequate thermal comfort conditions can be provided in free-running buildings in the climate of Santiago. The findings from field studies were crucial to understand occupants' preferences and space heating consumption behaviours, which turned to be in some extent over estimated since both thermal expectations and consumption levels were remarkably low. The underlying problem was then, thermal comfort itself, followed by occupants' limited choice to afford clean and safe energy sources. Results from parametric simulations demonstrated that through simple passive heating and cooling design techniques thermal comfort could

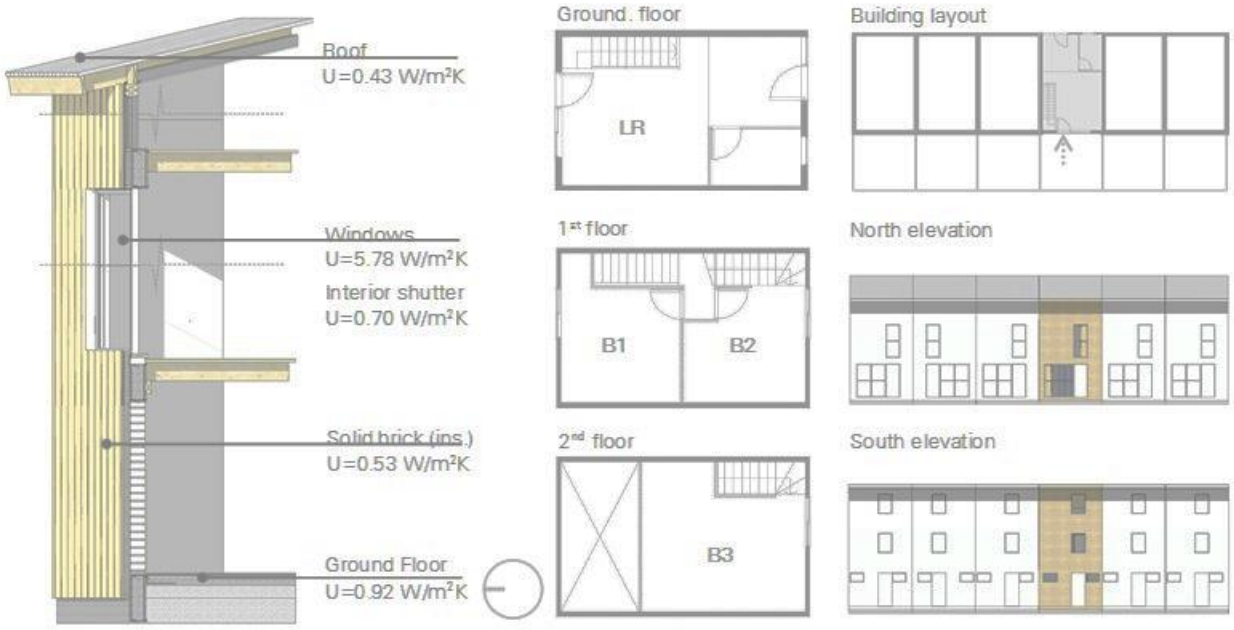

Figure 4. Optimized case study, plans and construction specifications.

be provided within minimum budget allocations, questioning the role of government authorities to ensure adequate housing conditions. The potential to reduce space heating down to nearly zero and provide thermal comfort all year-round could represent a significant contribution to improve indoor environmental performance and the quality of life of the urban poor, as well as open the debate towards energy autonomy by replacing combustion fuels with clean energy powered by solar energy technologies

ACKNOWLEDGMENTS

This study was carried out as part of a PhD thesis at the *Architectural Association School of Architecture* in London, UK. The author would like to thank to Prof. Simos Yannas and Prof. Paula Cadima for their supervision, support and fruitful advice. This research was supported by the National Commission for Scientific and Technological Research (CONICYT).

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Session 6E : Material technology

PLEA2014: Day 2, Wednesday, December 17
14:10 - 15:50, Faith - Knowledge Consortium of Gujarat

Sustainable Design and Construction of a Prefab Housing System with High Performance

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ABSTRACT

This paper aims to conduct an empirical test-bed research to improve design and construction process of the prefab multi-unit housing accommodating 50 college students, based on integrated co-works with different stake-holders (clients, architects, builders) and involving non-profit organization such as Habitat for Humanity Seoul. The purpose of the study is not only to develope optimal design technologies for the higher thermal efficiency but also to identify the ways in which the prefab houses could be supplied for low income groups.

INTRODUCTION

In Seoul, the capital of the Republic of Korea, the urban area developed to be quite overcrowded due to rapid economic growth and urbanization. After 2000, the population of Seoul had a steady while the number of households increased. This is because of the shift in the nuclear family composition, in which single or two-person households became more typical. With this, a housing shortage occurred in the urban area due to the increase in the number of households. The major concern in this housing shortage due to urbanization is the autonomy of the socially disadvantaged. As they are weak in terms of social standing, their residential environment is very poor. Therefore, in all levels of society the interest in the disadvantaged has increased, and diverse housing welfare projects for the socially disadvantaged as a low income group are actively being implemented. With this, the improvement of the residential environment is also becoming a critical issue.

In Korea, modular construction, which was presented for the first time in 2003, is proposed as one of the solutions to resolve this problem. The prefabricated house was presented as an alternative to resolve the problem of housing distribution for low income residents and socially disadvantaged persons in the urban area, and the current modular construction method that was introduced to Korea over 10 years ago is rapidly growing and is also recognized as a new construction system.[6]

Modular housing has become a very interesting issue, not only in Korea but also in other countries. In Korea, the modular construction system is generally applied for a range of purposes such as residences, commercial buildings, schools, hospitals, increasing during its short 10-year history, but there are still many problems to resolve.[7] This research focuses on potential applicability of the prefabricated house and the high-quality house distribution based on an empirical study on the modular house as a future method of residential construction with great potential.

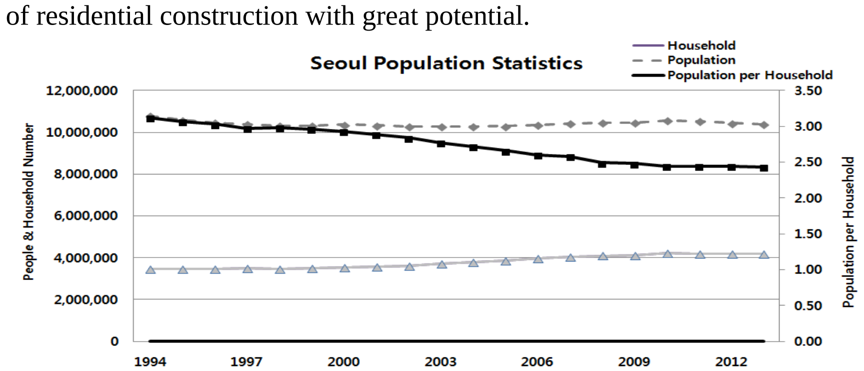


Figure 1. Seoul Population Statistics (National Statistical Office of Korea)

Author A is a Gerneral Manager, Author B is a Director, Author D is President at KRIEA(Korea Reserch Institue of Eco-Enviromental Architecture), Seoul, Korea. Author C is CEO at POSCO A&C, Seoul, Korea.

Background to Domestic Prefab System Housing

Most of the domestic modular houses from 2003 to 2008 were applied for education and military facilities, as the special characteristics of the modular construction were suitable to these applications. In modular construction the construction period is reduced, demolition and reuse after the life/duration of the building is easy and the application of new methods according to new policies is easier, as they are public facilities. In Korea since 2000, modular construction has been applied in different sectors such as for export, residence, the 2nd Antarctic Base, etc., and particularly in the residential sector, the Ministry of Land, Infrastructure and Transport revised the 'Industrialized Residence Acknowledgment Standard' for the first time in 2006 to enable the application of modular construction[7].

The residential sector in modular construction covers all areas, such as detached house, dormitory, small rental house, and mid-to-high-rise residences. This research will look at a 50-person capacity university dormitory, built recently with the modular construction method that has been gaining attention. Based on the above case, this research proposes the possibility of a model of house distribution for low-income groups through the cooperation of the government and private sector, by implementing an empirical study on a residence for students migrating from other provinces.

Characteristics and Need for A Prefab System Housing supply

The modular construction system is comprised of the factory manufacture/process of frameworks, electric works, construction equipment works and finishing and the assembly and installation of prefabricated parts on-site, the strongest point of which is the reduction of the construction period, procurement of equal/standardized construction quality, easy demolition process for aged buildings and the reusability of subsidiary materials. It can properly respond to working environment avoidance and to the demand for a reduced construction period. Also, through materials and specifications standardization in the factory the quality is uniform based on automated production technology.

The factory-manufactured prefabricated house is classified into different types according to the distribution and construction method, but the definition in this research is as follows:[8]

- Modular House : House composed of prefabricated parts that is constructed according to the local government or regulation of the construction site. House installed with module units transported from the factory to site.

When the material process and construction are fully performed on-site, problems can emerge such as deterioration of construction quality, increase in the construction price and extension of construction period, etc. In current domestic modular construction, the modules are generally manufactured for site construction, and therefore improvements in production efficiency are required.[2] Thus, even when the modules are assembled in the factory, the necessary materials must be detailed and standardized for every order/phase from the module manufacture and installation for an easier construction process. This will shorten the site construction period and improve the quality. The reduction of the construction period and improvement in quality results in a cost reduction, and this is the strongest point of the prefabricated house. Figure 3. shows a comparison of construction price composition between the British site construction method and the small and large modular method (OSM: Off-Site Manufacturing). The materials cost in the general modular method is larger than in the existing site construction method, in which the wall and floor of the modular house is basically formed by 2 floors.

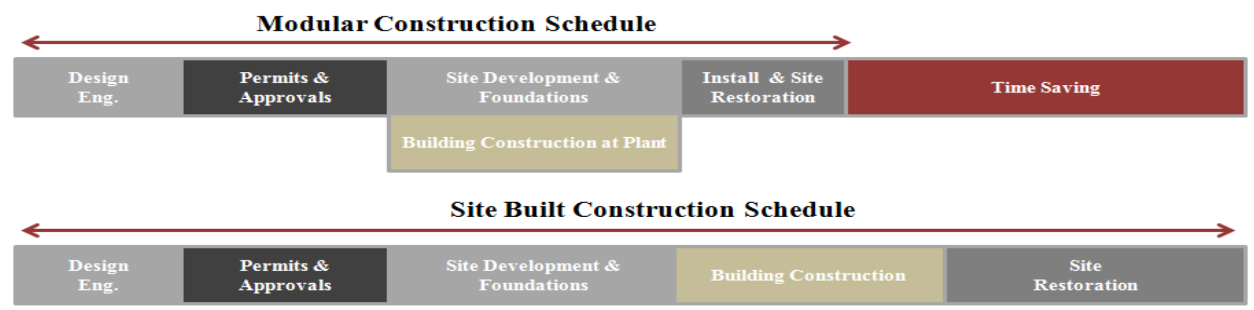


Figure 2. Advantages of a Modular Construction Schedule

Therefore, when the modular method is applied it must be considered that the material quantity is higher than in the existing site method. However, the reduction in unit price for quantity purchase, and reduction of loss on site can be considered as another strength of the modular method

Also, in the case of this factory-manufactured prefabricated houses, the building using of identical and standardized Materials simplifies the dismentlement at the end of the life, therefore the reuse value is also excellent due to the subordinate materials. This excellent reusability is a critical factor of the eco-construction method that may overcome the faults of waste production in the existing construction method.

In Korea the modular construction system includes reinforced concrete floor plate, and wet process as fire-proof paint in the ground plate phase considering the domestic residential environment. As shown in Figure 4, the modular construction system of this research requires production improvement and wet processes; sufficient design considerations, construction process and manufacturing planning to prevent cost increase for buildings over 5 floors, for which 2 or more hours of fire-proof treatment is required.[1]

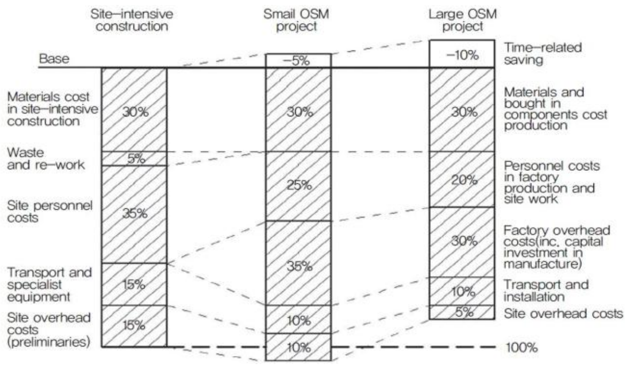


Figure 3. Comparison of Modular Construction Cost

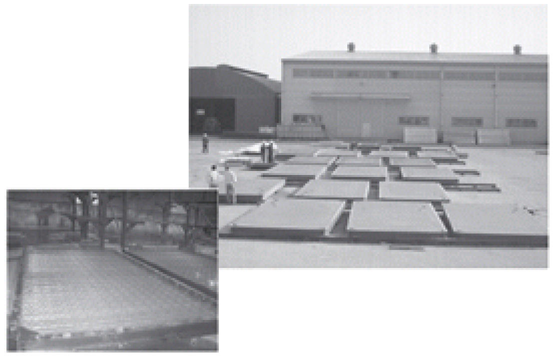


Figure 4. Deck Plate & Wet Construction Methods Case

CASE STUDY

"The Dreaming Attic for Student Residence CY"

As stated in Figure 5, Seoul is currently the city with the highest population density among all cities in OECD countries, at 16,700 person/㎢. This is 3 times denser than London. Many students come to the city to study in different universities but considering this high population density, it is actually difficult to satisfy the demand for student housing, placing a burden on the students. For this reason a project was implemented in which prefabricated houses were constructed on top of public parking lots managed by local governments to increase the added value of public spaces, and these were distributed to the socially disadvantaged in the form of rental houses. This became an object of empirical study as an alternative to using the ground space of the public parking lot, an indispensable facility in every urban area. Actually, the Dreaming Attic for Student Residence CY, which was completed in February 2014, is a representative case in which the NGO, Habitat for Humanity Seoul and Seodaemun district office cooperated to expand a building of 1F and 1 basement where there is a public parking lot for residents of the area into a 1 basement and 4-floor apartment building with housing units from the second floor to the fourth.

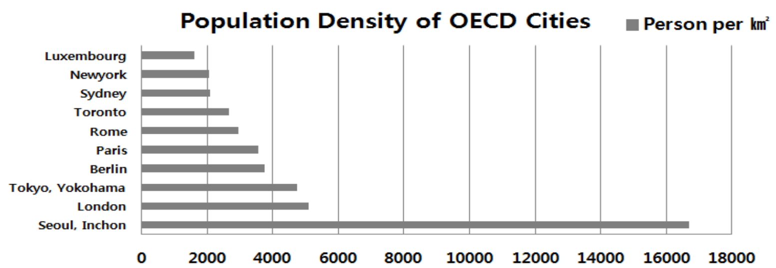


Figure 5. Population Density of OECD Cities (per/㎢)

Residents were strictly selected from nearby university students, and provided with a pleasant residential environment at a low cost. Figure 6 shows the assembly phase of the actual construction process. The project was implemented through cooperation between the NGO, the local government, the constructor and the module manufacturer to resolve the parking problem and to distribute low-cost, pleasant residences.

PERFORMANCE ANALYSIS & DEVELOPMENT

Environmental Performance of Prefab System Housing

Korea's Construction Act regulates the heat transmission coefficient in the basic insulation sector. Also, apartment buildings with 500 units or more are assessed in terms of preventing condensation to secure an adequate interior thermo-residential environment. In the anti-sweating performance assessment the value must be lower than the standard as the TDR (Temperature Difference Ratio) as stated in Equation 1. <Table 2> calculated the indoor minimum surface temperature of the wall using the computer simulation program PYSIBEL Trisco Ver.12 to interpret the electric heat of the wall. It was found that the weakest/poorest right angle TDR satisfied the domestic standard by scoring 0.233, showing performance equal to that of general apartment buildings built with reinforced concrete. The high-performance insulation effect of the prefabricated house secured a good indoor thermal environment, a reduced construction period and economic advantages. Given that the domestic climate has a clear difference in terms of the four seasons, a higher insulation performance is required when compared to prefabricated houses used in other countries. Table 3 shows the legal limits of the domestic apartment anti-sweating design standard. The target building of this research satisfies the existing apartment building standards and demonstrated an insulation performance similar to that of general residential buildings. While higher insulation performance can be secured, this will increase the basic unit price of the construction, and therefore we only showed the most optimal insulation performance.

Table 1. Introduction of Case Study ("Dreaming Attic for Students of CY")

Classification	Contents	View
Building Name	Dreaming Attic of CY	
Address	98-13, Cheonyeon-dong, Seodaemun-gu, Seoul, Korea	
Total Floor Area	785.53 ㎡	
Building Scale	B1F, 4F (B1F, 1F - Parking Area)	

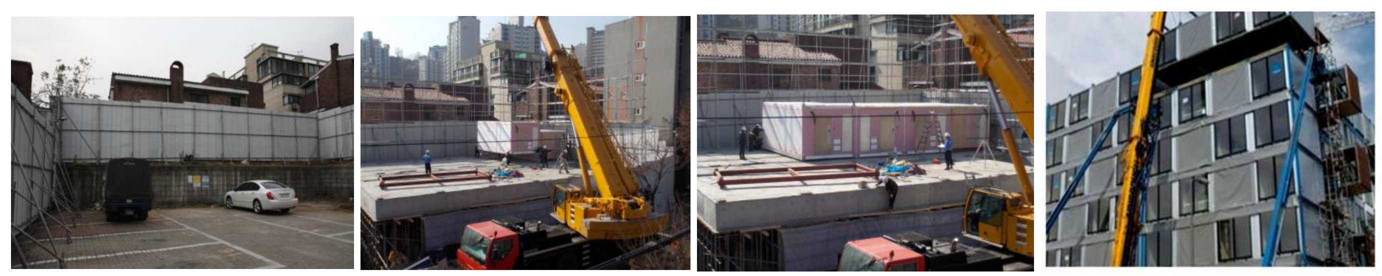


Figure 6. Modular Field Construction Case

$$TDR = \frac{T_i - T_m}{T_i - T_o} \quad \text{- Equation 1}$$

TDR : Temperature Difference Ratio

Tm : Indoor Minimum Surface Temperature (℃)

Ti : Indoor Air Temperature (℃)

To : Indoor Air Temperature (℃)

Table 2. Insulation Performance of Wall Junction (Prefab System Housing)

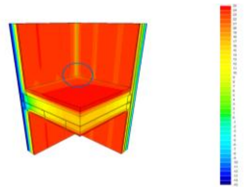
<table>
<tr><th>Plan</th><th colspan="3">Simulation Result (PYSIBEL Trisco)</th></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td>Heat Transmission Coefficient :</td><td>K : 0.27 W/㎡•K</td></tr>
<tr><td>TDR Standard</td><td>0.250</td></tr>
<tr><td>TDR (Ti:25, To:-15)</td><td>0.233</td></tr>
<tr><td>TDR (Ti:20 To:-15)</td><td>0.232</td></tr>
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Table 3. Standard of Assessments to Prevent Condensation of Apartment Housing

Region			TDR Value		
			Ⅰ Area (North)	Ⅱ Area (Middle)	Ⅲ Area (South)
Gate	Exterior Door Fire Door	Door	0.30	0.33	0.38
		Door Frame	0.22	0.24	0.27
Wall Junction			0.23	0.25	0.28
Exterior Window		Center of Glass	0.16 (0.16)	0.18 (0.18)	0.20 (0.24)
		Corner of Glass	0.22 (0.26)	0.24 (0.29)	0.27 (0.32)
		Window Frame	0.25 (0.30)	0.28 (0.33)	0.32 (0.38)

A New Housing Supply Model for Low-income Groups

In existing construction projects there were economic problems and difficulties in site selection. These difficulties resulted in an increased construction price, and there was a perception that the prefabricated houses were expensive; therefore, it was necessary to change that perception. The new project model, "Dreaming Attic for Student Residence CY," is indispensable for presenting the necessity of prefabricated housing and guaranteeing the welfare cooperation for all of society. But it is a fact that the investment required of the government and enterprises is still a problem to resolve. In addition, the problem of management after construction is significant. It is important to provide more benefits to the socially disadvantaged, and to distribute these equally through transparent management and administration.

As we can see in Figure 7, through this project model the government, NGO, constructor, module manufacturer, the people and the disadvantaged will all gain great benefits. The government will have the benefit of a direct solution to a social problem, the enterprise will gain the advantage of experience through manufacturing and constructing prefabricated houses, changing perceptions of prefabricated houses and making a disadvantaged will all gain great benefits. The government will have the benefit of a direct solution to a social problem, the enterprise will gain the advantage of experience through manufacturing and constructing prefabricated houses, changing perceptions of prefabricated houses and making a social contribution. Above all, through the cooperation and social contribution of the government, NGO, constructor and manufacturer, more socially disadvantaged persons will receive more benefits, producing positive effects in general.

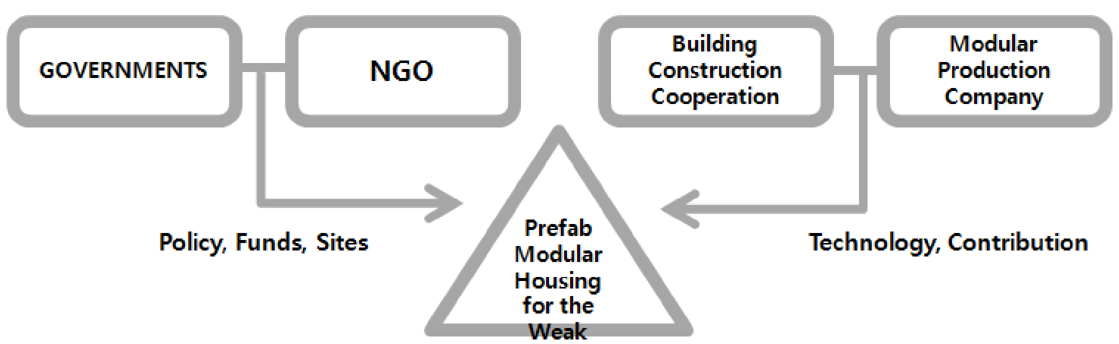

Figure 7. Concept of a Housing Supply Model

CONCLUSION

In this research we presented a project model based on the above-described empirical cases for a wider application and diffusion of prefabricated houses. The application of prefabricated system housing can be an excellent alternative that satisfies the demands resulting from high population density, the increase of single-person households, and the need for inexpensive small-unit housing and demands for better residential environment, etc. Nowadays, a better residential environment with uniform performance and quality can be provided through optimal performance evaluation within a scope where excessive design is avoided by reducing the construction period through the use of prefabricated houses.

In the prefabricated housing system, construction, equipment and electric works excluding civil and landscape works are performed in factory by the manufacturer, therefore the role allocation between the contractor and subcontractor is very different from that of existing site construction methods. Thus, with the development of the new module technology, the module manufacturer performs the new project model incorporated with the constructor and so the benefit is provided to everyone and is made available to society through its application in a housing welfare project. It will no longer be a simple economic activity, but an indispensable housing welfare project model for low income and disadvantaged persons and an excellent response to the government policies.

In addition to the public parking lot, it is necessary to expand the project by procuring diverse project sites to provide more benefits for the disadvantaged. This project model is applicable not only in Korea but in all other countries, and considering that it strengthens the benefits of prefabricated housing it will be an ideal alternative for us to open the future. The modular construction system which guarantees economic advantages based on a high technological level and experience offers a new paradigm in housing welfare projects through the improvement of the residential environment for low-income and disadvantaged persons living in inefficient residential spaces, through the cooperation and assistance of the government and diverse NGOs, and the probability of its application was clearly certified. More interest needs to be taken in housing provision methods for low-income and disadvanted persons.

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Carbon dioxide emissions of green roofing – case study in southern Brazil

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ABSTRACT

Nowadays there are several efforts in define carbon dioxide emissions of buildings components and materials. This data shall be in accordance with local building technology or methods of construction. Therefore studies of local alternatives are important. This work presents results of carbon dioxide emissions for two solutions of usual green roofing in southern Brazil. The method considers production of main inputs, road transport from point of sale to the site of construction, workmanship transport. The two green roofs are compared with ceramic and asbestos-cement tiles solution. The data were obtained by surveys, interviews with owners and scientific literature. The building materials, distances of transport were quantified. The results demonstrate that the carbon dioxide emissions are larger than the emissions of the conventional roofing and the main contribution is due to the road transport of components and materials from the point of sale to the site of construction. However, we must consider that the green roofing has a high potential for the carbon sequestration, promotes thermal resistance, humidify and filter the air, reduce the urban surface temperatures.

INTRODUCTION

Civil construction is responsible for 40% of energy demand and 38% of air emissions that contribute for global warming. However there is 30% to 50% of potential for reduction of energy consumption and 35% for reduction of air emissions [1]. In Brazil the civil construction has substantial participation on greenhouse gases. Excluding the carbon dioxide (CO_2) emitted by burnoffs, the building construction represents a quarter of significant air emissions, either by chemical reactions of industrial processes of materials or by the energy sources involved in these industrial processes [2]. Further, the materials transportation, mainly by roads with fossil fuel, contributes significantly for CO_2 emissions [3]. Table 1 illustrates the CO_2 emissions coefficient (Kg CO_2 eq) for the mainly fuels used in Brazil [2].

Table 1. CO_2 emissions due to some fuel sources

fuel source	emissões de CO2 (kg CO_2/GJ)
diesel oil	79,8
natural gas	50,6
petroleum coke	72,6
other sources derived of petroleum	0,0
electrical energy	18,1
fuel wood	81,6

Table 2 ilustrates the embodied energy in some construction materials expressed in percentage according to [2]. The use of energy in industrial processes also significantly contributes for CO_2

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emissions; therefore the consideration of production emissions is important in the life cycle of construction materials.

Table 2. Percentage of embodied energy due to source for some materials construction

material/source	diesel oil	natural gas	coke	other sources	electrical energy	wood
sand	99				1	
mortar	86				4	
ceramic	4				2	85
cement	3		61		12	
asbestos	84				14	
waterproofing substances	10	30		34	26	
polymer	10	30		34	26	

The choice of the best environmentaly sound building technologies promotes the envinronmental impacts reduction, such as energy consumption and toxical gases emissions [4]. Technologies must be in accordance with local and regional traditional technology and disponibility of natural resources and industrialized local materials. Therefore the study of local solutions is important to achieve the building environmental performance.

In this study green roofs are understood as vegetal layer intentionally incorporate on top of buildings. They have been pointed as alternatives more sustainable if compared with conventional roofs, such as tile and asbestos-cement roofs. There are many vantages associated to green roofing, such as natural top ground, life cycle extended, better thermal performance and consequently building occupants comfort more acceptable, reduction of urban heat-island effect, carbon sequestration, among others [5]; [6].

A negative factor associated to green roofs regards to the water comsuption. This aspect is not studied in this research, but some authors pointed that there are benefits to manage stormwater in order to restore the capacity of water retation lost by excessive paving of soil in cities [7]. It is possible to reduce about 60% of runoff for rain water captation. Further, the use os plant species that require little irrigation can be reduce the water comsuption, one of negative factors associated to green roofing [7].

In Brazil some studies about green roofing has been already enhanced. Through computational simulation [8] and prototypes submitted to measurement [9] the potential of green roofs for water catchment and retention was verified. Also was verified the viability of green roofs for low-cost housing [10]. A research concerning to occupants' satisfaction indicated that the need for constant maintenance was one of the problems more mentioned [11]. However there are a few studies about the environmental impacts of green roofs mainly referring to CO_2 emissions.

This study aims to contribute to this issue through the quantification of carbon dioxide emissions of four roofs commonly built in Brazil, two green roofs built in two different regions, provincial medium town and industrial city, and two conventional ceramic and asbestos-cement roofing in order to compare their environmental performance due to carbon dioxide emissions. Additionaly the carbon sequestration potential was quantified in order to verify this important contribution of green roofs for sound environments.

METHOD

Selected green roofs

The green roofs are approximately 200km away each other (with different proximities of industries that produce the building materials involved), they are selected in accordance with the occupants permission to access the necessary data for the life cycle inventory, the construction system involves little labour and artisanal method. The ceramic tiles and asbestos-cement roof do not have the same thermal insulation, since the owners have chosen the green roofs for aesthetic and environmental sustainability, without refering their thermal performance. The Figure 1 ilustrates the green roofs studied.

Figure 1 (a) Layers of green roof located in a big city, (b) in a mendium town in country.

Inventory

The data for the inventory were obtained from interviews with the owners of analysed houses, invoices, private diaries and reports elaborated by owners, regular direct observations, *in situ* measurements during building production process. Layers constituting the roofs, quantitative of materials, products' points of sale, places of production of listed materials, distances of production, sale and jobsite area, materials modal transportation were collected. The demand of labour and the distances between jobsite, workers housing, means of transport also were measured from interviews and data registered by owners. The distances were obtained from virtual maps.

Quantification of carbon dioxide emissions

Contribution of different energy inputs was defined for constituting layers and materials. For each material, the total embodied energy CE was computed, the percentage of each significant source present in material production was also computed, obtained from [2], and is represented by P%. The individual contribution of each source was obtained by the product of total embodied energy and the individual carbon dioxide source contribution named $coef_{CO2source}$ obtained from [2]. The somatory of individual contributions is the total carbon dioxide emissions E_{CO2} represented by Equation 1.

$$E_{CO2} = \Sigma[CE\ (MJ) \times P_{\%}/100 \times coef_{CO2source}] \quad (1)$$

where

E_{CO2} is the carbon dioxide emission, kg CO_2;
CE is the contribution of different energy inputs, MJ;
$P_{\%}$ is the percentage of a kind energy in production process, %;
$coef_{CO2source}$ is an index representative of CO_2 emission of energy source, kg CO_2/MJ.

Since it was not possible to determine the characteristics of vehicle used as mean of transport and the kind of fuel, the indices established by [3], which studied carbon dioxide emissions for Brazilian road transport, were considered as reference. The mentioned author considers that it is possible to determine the CO_2 emissions with an admissible error considering the distances and a medium factor according to type of transport. The carbon dioxide emission index for transportation from place of production to place of sale, with heavy road transport, was considered equal to 0.895 kg CO_2 / km [3] since that is the conventional transport for construction materials in Brazil; for transportation from place of sale to jobplace (conventionaly transport of light load in Brazil) was considered equal to 0.106 kg CO_2 / km [3] by the same previus reason. The carbon dioxide emission related to mean transport for each material was calculated using the Equation 2.

$$\text{total emission material transport} = \text{emission}_{CO2/km} \text{ x } \text{distance}_{prod \rightarrow sale} + \text{emission}_{CO2/km} \text{ x } \text{distance}_{sale \rightarrow jobplace} \quad (2)$$

The Equation 3 was used for calculating the emissions due to transport of workers. The dioxide carbon emission index per day for mean transport was considered equal to 0.106 kg CO_2 / km.day, embodied energy was considered equal to 0.0015 MJ / kg and the weight for worker is equal to 70kg.

$$WT_{CO2} = EE \text{ x total weight x } distance_{home \rightarrow workjob} \text{ x worked days x } emission_{CO2/km}$$

where

WT_{CO2} is the total emission worker transport, kg CO_2;

EE is the embodied energy, MJ/kg;

$distance_{home \rightarrow workjob}$ is the distance between the home and the workplace, km;

total weight is the transported weight, kg;

$emission_{CO2/km}$ is the carbon dioxide emissions per kilometer due to worker transport, CO_2/km.

Carbon sequestration

Addionally the potential for carbon sequestration was calculated in order to verify one of main environmental contribution of green roofing. The larger carbon sequestration for grass with 20cm of substrate for plant growth is considered equal to 0.945 $kgCO_2$ / (m^2.year) [12]. The mentioned value was multiplied for the area of each green roof. Total calculated carbon dioxide emission for each green roof was divided for the index in order to obtain the number of years necessary to sequester.

RESULTS

Table 3 presents the carbon dioxide emissions due to materials production and Table 4 emissions due to transport for the green roof located at the big city (green roof 1) with 28,41m^2 of surface.

Table 3. Carbon dioxide emissions due to material production for green roof 1.

layer	area or volume	density (kg/m^3)	mass (kg)	relative embodied energy (MJ/kg)	total embodied energy (MJ)	CO_2 emissions ($kgCO_2$)
asphalt fabric 4mm	28.41m^2	1.125	127.84	51.00	6,519.84	342.62
crushed rock	0.28m^3	1.400	397.74	0.15	59.66	4.21
sand	0.57m^3	1.470	835.25	0.05	41.76	3.31
organic soil	0.075m^3	1.600	120.00	0.00	0.00	-
soil	0.075m^3	1.400	105.00	0.00	0.00	-
garden grass 1 (60%)	16.93m^2	1.500	1,523.70	0.00	0.00	-
garden grass 2 (40%)	11.48m^2	1.500	1,033.20	0.00	0.00	-
total	-	-	4,142.73	-	6,621.26	350.14
total per m^2					**233.06MJ/m^2**	**12.32$kgCO_2/m^2$**

Table 4. Carbon dioxide emissions due to material transport for green roof 1.

layer	transport mode$_{prod \rightarrow sale}$	distance$_{prod \rightarrow sale}$ (km)	emission $CO_2$$_{prod \rightarrow sale}$ (CO_2 kg)	transport mode $_{sale \rightarrow jobplace}$	distance $_{sale \rightarrow jobplace}$ (km)	emission CO_2 $_{sale \rightarrow jobplace}$ (CO_2 kg)	CO_2 total layer emission ($KgCO_2$)
asphalt fabric 4mm	road	1.185	1,060.58	car	21.90	2.32	1,062.90
crushed rock	road	52	46.54	wheelbarrow	0.24	0	46.54
sand	road	52	46.54	wheelbarrow	0.24	0	46.54
organic soil	in situ	0	0.00	in situ	0.00	0	0.00
soil	road	77.2	69.09	car	10.90	1.16	70.25
garden grass 1 (60%)	road	68	60.86	car	10.90	1.16	62.02
garden grass 2 (40%)	in situ	0	0.00	car	13.40	1.42	1.42
-	-	1,434.2	1,283.61	-	-	57.58	1,289.66
total per m^2							**45.39kgCO$_2$/m^2**

The major emissions are due to asphalt fabric that is the component with industrial process more complex among the green roof layers; involves large energy inputs; with centralized production. Therefore replacement of that layer is a possibility in reducing de CO_2 impact.

Table 5 presents the carbon dioxide emissions due to worker transport for the green roof 1.

Table 5. Carbon dioxide emissions due to workers transport for green roof 1.

	weight of transported workers (kg)	distance$_{home \rightarrow workjob}$ (km)	worked days	transport mode	embodied energy (MJ)	CO_2 emission (kg CO_2)
owner	140 Kg	-	3	-	-	-
worker	140 Kg	15	1	car	10.815	1.59
total					10.815	1.59

For the ceramic tile roof built in the big city, the main contributions are due to production of ceramic tiles (481.17 $kgCO_2$) and due to transport of truss materials (peroba wood) (1,100.22 $kgCO_2$). In this case, the use of wood which production is strongly centralized (with environmental license) contributes significantly to carbon dioxide emissions.

For the asbestos-cement roof built in the same place, the main contributions are due to transport of truss materials (1,100,22 $kgCO_2$), since there are local industries that produce fibercement tiles.

Table 6 presents the carbon dioxide emissions due to materials production and Table 7 emissions due to transport for the green roof located at the medium town (green roof 2).

Table 6. Carbon dioxide emissions due to material production for green roof 2.

layer	area or volume	density (kg/m³)	mass (kg)	relative embodied energy (MJ/kg)	total embodied energy (MJ)	CO_2 emission ($kgCO_2$)
waterproofing	45.28 litres	1.3 (kg/l)	58.86	65.00	3,826.16	201.06
pebble crushing	2.3 m³	1000	2,300.00	0.00	0.00	0,00
waterproofing coating	56.6 m²	0.12	6.79	51.00	346.29	25.50
soil	3.4 m³	1,400	4,760.00	0.00	0.00	0.00
garden grass	56.6 m²	1,500	5,114.44	0.00	0.00	0.00
-	-	-	-	-	4,172.45	226.56
total per m^2					**73.72MJ/m^2**	**4.00kgCO$_2$/m^2**

Table 7. Carbon dioxide emissions due to material transport for green roof 2.

layer	transport mode prod→sale	distance prod→sale (km)	emission CO_2 prod→sale (CO_2 kg)	transport mode sale→ jobplace	distance sale→ jobplace (km)	emission CO_2 sale→ jobplace (CO_2 kg)	CO_2 total layer emission (CO_2 Kg)
waterproof.	road	1265	1,132.18	car	6.90	0.73	1,132.91
pebble crushing	in situ	0	0.00	-	0.00	0.00	0.00
waterproof. coating	road	1,431	1,280.75	car	6.90	0.73	1,281.48
soil	in situ	0	0.00	-	0.00	0.00	0.00
garden grass	road,	0	0.00	-	0.00	0.00	0.00
-	-	2,696	2,412.92	-	13.80	1.46	2,414.38
total per m^2							**42.66 kgCO_2/m^2**

Table 8 presents the carbon dioxide emissions due to worker transport for the green roof 2.

Table 8. Carbon dioxide emissions due to workers transport for green roof 2.

	weight of transported workers (kg)	distance$_{home \rightarrow workjob}$ (km)	worked days	transport mode	embodied energy (MJ)	CO_2 emission (kg CO_2)
owner	280 Kg	-	3	-	-	-
worker	280 Kg	11.4	1	car	8.2194	1.21
total					8.2194	1.21

In the same way of the precedent green roof 1, the major emissions are due to more industrialised component that is the waterproofing layers. The use of two waterproofing layers is critical for the poor performance of this roof.

For the ceramic tile roof built in the medium town, such as for the big city, the main contributions are due to production of ceramic tiles (958.12 kgCO_2) and due to transport of truss materials (peroba wood) (1,178.00 kgCO_2). In this case, the use of wood which production is strongly centralized (with environmental license) contributes significantly to carbon dioxide emissions.

For the asbestos-cement roof built in the medium town, the main contributions are due to transport of truss materials (1,178.00 kgCO_2). The incorporated cement in the asbestos tiles is responsible for 486.40 kgCO_2 emissions.

The Figure 3 illustrates the total emissions per square metres due to the six roofs, green, asbestos-cement, ceramic. In relation to transport materials both green roofs present lower performance than ceramic and cement-asbestos conventional roofs. This result is due to presence of layers based on fossil source (asphalt fabric and water proofing layer) with centralized production. In relation to carbon dioxide emissions produced from manufacturing the green roof 1 is more unsustainable due to asphalt fabric, presenting best performance only compared with the ceramic tile roof. Production of ceramic tiles envolves large energy for burning and transport due to their weight since this type of roofing has large embodied energy and carbon dioxide emissions. The cement-asbestos tile results in the best performance for the case study in the big town because there are local industries for this material. The three roofs type 2 located in the town far of production regions present the lower contribution in CO_2 emissions what is an unexpected result since is further away from production centers. This result demonstrates the importance of contextualized solutions. Green roof 2 is technically simpler; a despite of using a water proofing layer with large embodied energy and carbon dioxide emissions, it requires less amount of material to fullfil the same function comparatively with roof 1. The emissions associated to worker transport are insignificant compared to production and transport materials due to artisanal and auto-construction process, reforcing the use local workforce and techniques.

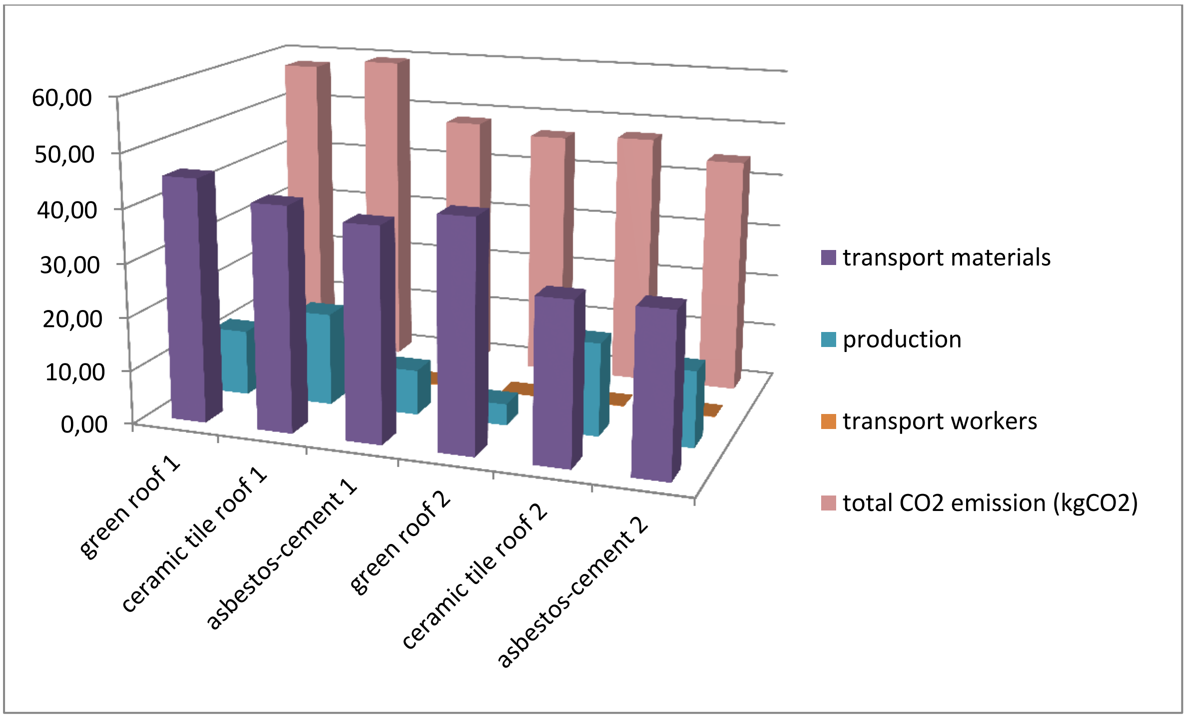

Figure 3 Partial and total CO_2 emissions due to different analised roofs per square metres.

Considering the three contributions analyzed, transport materials, production, and transport workers, there is little difference between the three roofing in the medium town, which is does not do in the case of roofing in the big city where the cement-asbestos is the best solution.

It takes the green roof 1 about 61 years for carbon sequestration due to production and transport of materials and workers. For the green roof 2, it takes about 50 years. These results demonstrate that the main benefit of green roof is obtained in very long time-lag, which counters to principal benefit associated to green roofs.

CONCLUSION

Through results the green roofs present large CO_2 emissions due to use of layers based on polymers or fossil source materials which production involves large embodied energy and several emissions that contributes for greenhouse. It pointed to need to replace the waterproofing layer based on fossil source for another one more environmentally sound. For the case studies illustred material transport is responsible for the largest emissions for six simulated roofing. Results reinforce the importance of choosing local and regional technologies, materials, and workforce. The cement-asbestos roof has the best performance relative to carbon dioxide emissions; it flies in the face of common sense in considering the green roof necessarily an environmently good solution. Furthermore, one of benefits associated to green roofs, the carbon sequestration, is reached in a long time opposing to general idea of sustainability.

Green roofing has been considered as a building system with low environmental impacts. The analyses of carbon dioxide emissions demonstrated that it has lower performance than the conventional solutions even if were regarded the potential for carbon sequestration. However the easiest solution adopted for the conventional roofing, without a thermal insulation, collaborate for the results achieved.

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Design and Testing out of an Insulating Floor Element, Composed of Recycled Rubber and Inert Demolition Waste

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ABSTRACT

Even if initially dominated by cost concerns, energy-awareness is today maturing towards a vision aimed at curtailing energy consumption and reducing carbon emissions.

In consideration of today's large amount of tyres being used and disposed of, the purpose of this research was to investigate options for utilising recycled rubber as a building material (in combination with inert demolition waste), namely as insulation in flooring elements such as tiles, such a mix could replace new underlay insulating materials typically having a higher embodied energy content. This paper evaluates the potential of recycling used tyres in specially fabricated floor tiles for different design mixes and evaluates the success/failure of such a building element as a floor finish.

The study also looks into the best combination of materials to form a durable, non-abrasive robust tile, yet also acting as a thermal and moisture barrier. An added value of the proposed tile is its acoustic property, where the shredded rubber makes it also resilient to impact and airborne noise. Its light colour also proves ideal for solar-exposed flat roofs, where, it is also aesthetically pleasing for the outdoor evening lifestyle in a Mediterranean climate.

INTRODUCTION

Since prehistoric times human beings have always searched for ways to protect themselves against the elements, first through the use of naturally formed shelters such as caves and then evolving into proper building-shaped constructed dwellings made using either naturally occurring materials extracted from the earth or man-made artificial materials. Through time, with the introduction of energy-intensive heating and cooling systems, energy consumption in buildings has however increased. This is requiring that new methods for making a building more energy efficient be researched and studied.

In this context, particular attention is being given by researchers not only to provide building elements with good thermal properties, *e.g.* low thermal transmittance which prevents high rates of heat transfer, but also to the fact that these building elements are made from materials, possibly recycled ones, having a low embodied energy. One such material is recycled rubber from end-of-life automotive tyres. Due to the heavy metals they contain, rubber tyres are a very problematic waste source. If disposed incorrectly, the chemicals they contain can contaminate ground water sources. Also, other problems arise from their size which makes it very hard and expensive to dispose of. To minimise volume burning them is an option, however today this is practically forbidden due to the toxic gases discharged into the atmosphere (typically carbon monoxide and sulphuric acid). This problem is aggravated by the fact that each year millions of tyres are consumed to meet vehicle road standards. If properly recycled, this rubber however, can be made

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to good use given its inherent thermal properties, which give it a low thermal conductivity value, ideal for use in building components.

Recycled Rubber Embodied energy

Material selection and technologies used in building construction should aim to achieve the building occupants expected performance as well as aiming to minimise the environmental impact as much as possible, not only in the context of reducing energy consumption during its lifetime, but throughout its lifecycle, starting off from its production to the time when it is disposed off. In this context, Table 1 shows the specific total embodied energy per kilogram of tyre material produced. The rubber used for the production of tyres has a very high embodied energy and therefore finding alternative uses, especially at the end of lifecycle, can be beneficial to the environment.

Table 1. Embodied energy and greenhouse emissions of manufactured rubber tyre

Material	Energy (MJ/kg)	Greenhouse ($kgCO_2/kg$)
Natural Rubber	8	0.4
Synthetic Rubber	110	5.0
Carbon Black	125	5.7
All other additives	100	8.2
Fabric	45	2.1
Steel Tyre Cord	36	3.2
Manufacture per kg	11.7	1.86
Total	**435.7**	**26.46**

Recycled Rubber as a Building Material

The use of recycled rubber as a building material is not something completely new and various attempts have been made to make use of this resource to improve the properties of a building element.

Recycled Rubber as Asphalt A study made by the University of Toronto (Way *et al.*, 2011) was carried out to investigate the use of recycled shredded rubber in normal road asphalt. Metro Toronto Roads and Traffic Department resurfaced five main roads using this new mix and no serious difficulties were encountered. In actual fact it was noticed that the new roads offered a greater durability with a lower requirement for maintenance and a subsequent higher expected lifetime, and a better overall performance with respect to road safety due to a higher frictional response (Piggott and Woodhams, 1979).

Recycled Rubber Floorings Rubber floorings is another use for recycled tyre rubber. Floor tiles made using recycled rubber are relatively soft, despite them being used for commercial grade durability standards. Such properties in fact render these floor tiles a particular viable option for flooring systems in retail outlets were people walk for long periods of time and in playrooms and public spaces where the impact absorption properties of such floor tiles, adds an element of safety for children playing in these spaces. Gyms also often use this product as it absorbs sound made from falling weights and the continuous uses of cardio machines. Finally, rubber floorings can also be used in bedrooms and other living spaces as an alternative to fitted carpets (Ecosurface, 2014).

THE NEW BUILDING ELEMENT PROPOSED

The aim of this research was to create a new type of roof tile using recycled material generated from vehicle worn out tyres and inert demolition waste, originally both intended to be disposed of, and both requiring large volumes at waste disposal facilities. In warm climates where flat roofs are the norm, solar ingress through the roof is a main source for heat gains inside buildings, since these receive the beating of a persistent scorching sun in summer, unlike walls that could be typically shaded. Therefore the provision of thermally isolating materials as part of roofing elements is of primary importance for reducing such solar gains. This is particularly important in a hot Mediterranean Island such as Malta.

Element Composition

Aerated concrete was used as the base material with shredded rubber from recycled tyres added in varying percentages, namely 20%, 30% and 60% to constitute different tile mixes. Aerated concrete, classified as a lightweight concrete, is made up by mixing concrete with an aerating agent which causes the creation of a number of air voids inside the mix. The main advantage of this type of concrete is its lightweight composition and the high degree of thermal resistance which reduces the need of adding extra insulation to improve the thermal performance of a building element. The tile, having dimensions of 300mm by 300mm, was finished with a thin layer of a glass fibre coating. Polyester resin fibreglass is an impermeable material, thus adding this element would benefit the tile from making it water proof. Another added benefit of the fibreglass finish is in terms of its strength. Since the fiberglass contains and supports the aerated concrete which is considered to be weak, due to the presence of a large amount of air cavities, the tile performs better with regards to flexural strength, as the fibreglass encloses the tile creating a more compact system of materials.

SPECIMEN BUILDING AND TESTING

This section focuses on the procedure adopted in building and testing the proposed tile using a parametric methodology, whereby a number of design mixes were produced to analyse the effect of a selection of parameters on the thermal performance of the tile.

Test Specimen Preparation and Construction

Preparing the specimen involved using a mixture of recycled rubber granules, sand, cement and water to create the base constituents for the recycled rubber-infused aerated concrete mix. For the aeration process aluminium powder and sodium hydroxide were then added. In order to allow enough time for the aeration process a popular retarder was added to the mixture, to slow down the cement hardening reaction process. Once the mixture was prepared and the aeration process started, the tiles were left for two days to set within a specially designed mould. Once ready the moulds were dismantled revealing the tile. A fibreglass coating of around 4mm thickness was applied at the end of the process to give the tile a smooth clean dust-free, cream-white finish. Figure 1 shows a schematic of the different layers of the tile (inverted).

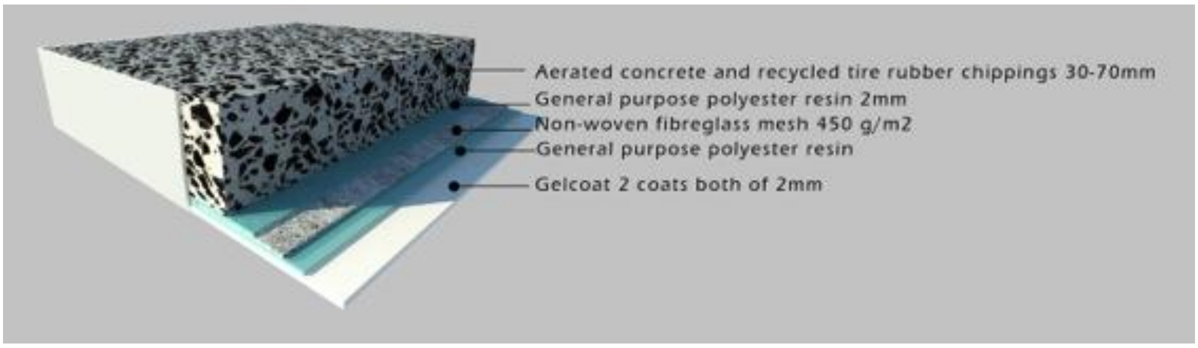

Figure 1 Schematic of propsed tile (inverted as cast)

Testing the different design variables

As part of the testing procedure various design mixes were produced with the intent of testing the variability in thermal performance of the different proposed design variables. The main variable parameters tested were the rubber percentage and the tile thickness, with each variable being tested for three possible permutations for a total of nine combinations. The rubber percentage was varied between 20%, 30% and 60% of the design mix. For each rubber percentage three tile thicknesses were moulded, namely 45mm, 70mm and 90mm thickness. Table 2 summaries the different combinations created.

Table 2. Tile Mix Material Values

Rubber Percentage (%)	*Thickness (mm)*	*Sand (g)*	*Cement (g)*	*Water (g)*	*Rubber (g)*	*Aluminium (g)*	*Sodium Hydroxide (g)*	*Retarder (g)*
20	**45**	2	900	54	460	22	22	15
30	**45**	2	820	49	690	20	20	12
60	**45**	1	615	37	960	17	17	10
20	**70**	3	1200	72	640	32	24	17
30	**70**	3	1150	69	900	30	22	15
60	**70**	2	900	54	1380	22	20	13
20	**90**	4	1780	10	920	46	35	22
30	**90**	4	1650	99	1290	44	32	20
60	**90**	3	1300	78	2016	34	25	18

Testing inside the Hot Box

The testing of the tiles was carried out using an established insulated Hot Box previously used and tested in the Environmental Lab. This was originally built according to BS EN 8990:1996 (BSI, 1996). The Hot Box was constructed using concrete block work, filled with C30 concrete with all joints sealed to reduce any heat losses. In order to measure the overall heat transmittance (U-Value) of horizontal building elements the Hot Box is divided into two chambers, a controlled artificially heated '*hot*' chamber and an underlying '*cold*' chamber, separated by a typical Maltese roof construction, as shown in Figure 2.

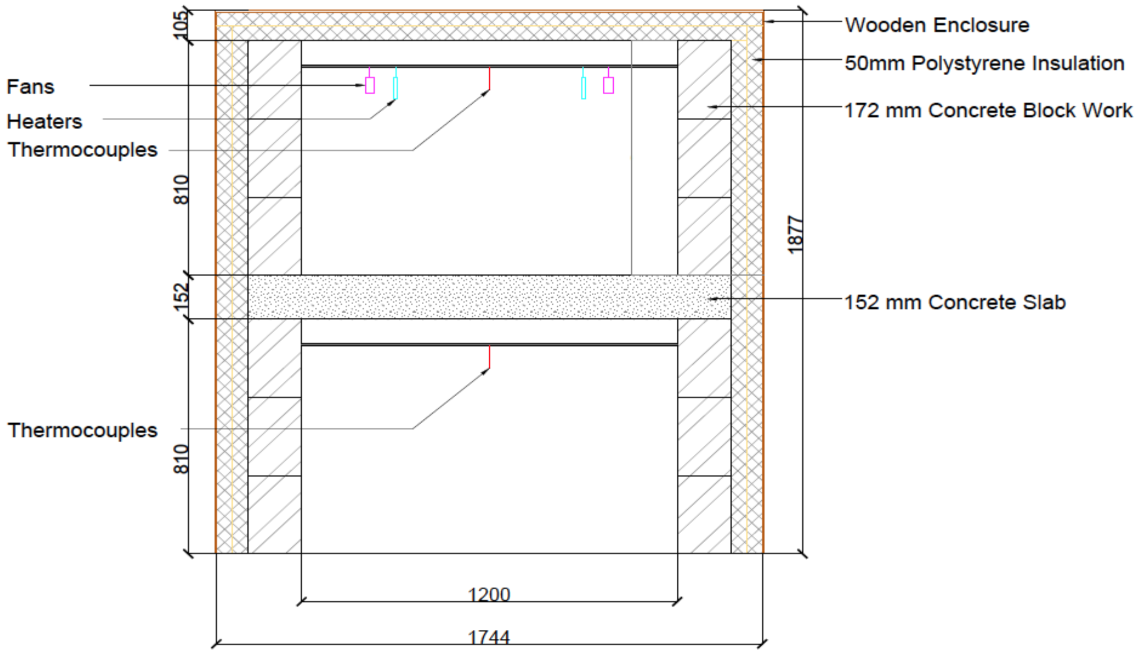

Figure 2 Sectional Elevation of the Hot Box

The top-most warm side of the Hot Box was set up with four heaters, grid-lined, each having a power of 700 Watts suspended from a steel square mesh connected to the top part of the Hot Box, as the grid-matrix. Four fans were also connected to the mesh to create a continuous air flow thus creating an evenly distributed temperature profile throughout the interior warm side of the Hot Box.

Each combination of designed tile mix was tested inside the Hot Box, by laying the tiles on top of the '*hot*' chamber floor, as shown in Figure 3, and measuring the temperature difference between the two chambers once steady-state is obtained.

Figure 3 Hot Box set-up comprising the composite tile, 50mm globigerina sand, damproof membrane

In order to measure the temperature difference across the two chambers a total of 18 thermocouples were used. In the top '*hot*' chamber, eight thermocouples were fixed on top of the tile surface while a ninth thermocouple was suspended in mid-air to measure the air temperature inside the chamber. The setup was mirrored in the '*cold*' chamber. Each thermocouple was connected to a central data logger which recorded the readings from each individual thermocouple. The ambient room temperature was also monitored.

Surface temperature readings were recorded at 15-minute intervals until a until the hot box reached steady state i.e. the temperature gradient between both chambers remains at a constant rate. Once the hot box reached this thermal status, the steady state the temperature difference was calculated.

The composite tiles laid and tested into nine different categories. Each category had sixteen similar tiles, (4x4no.x 300mm each tile), fitted in the calibrated hot box. Each category has a variation in either thickness or rubber content as indicated in subsequent output results, Figure 4.

RESULTS

Figure 4 shows how the overall heat transmittance, the building's element U-value, as it varies with respect to changes in the recycled rubber content and the tile thickness. It can be observed that the major governing factor in decreasing the U-value of the proposed tile is by varying the thickness. As the thickness increases the lower is the U-value obtained. Increasing the rubber content also decreased the U-value but to a lower extent.

The main advantage of this design mix is that the rubber can be used to increase the volume of the tile, replacing quarried limestone sand, thus saving embodied energy, with the added benefit of making the tile more thermally resistive. With an increase in rubber content from 20% to 30%, the U-value dropped by -0.05, -0.06 and -0.13W/m^{2}K for the 45, 70, 90mm tiles respectively. With an increase from 30% to 60% further drops of -0.07, -0.02 and -0.03 W/m^{2}K were noted for the 45, 70, 90mm tiles respectively, as can be seen in the summarised values in Table 3.

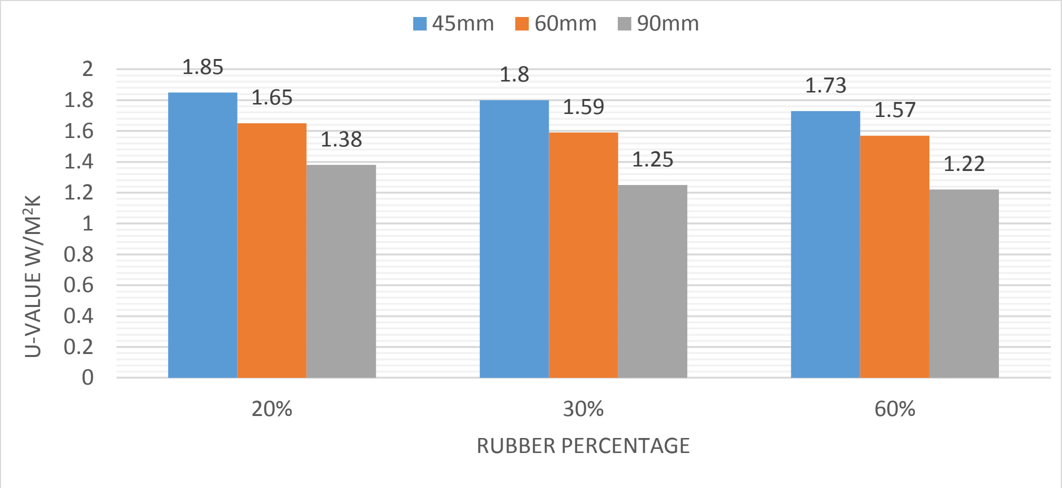

Figure 4 U-value vs. Percentage rubber content for the 45mm, 60mm, and 90mm thick tiles

Table 3. Percentage Rubber content *vs.* Tile Thickness & respective U-values

Rubber Ratio	**20%**	**30%**	**60%**
45mm tile	1.85 W/m^2K	1.80 W/m^2K	1.73 W/m^2K
Change in U-value		-0.05	-0.07
70mm tile	1.65	1.59	1.57
Change in U-value		-0.06	-0.03
90mm tile	1.38	1.25	1.22
Change in U-value		-0.13	-0.03

This further indicates that with a change of mass the drop in U-value is more pronounced than with the increase in rubber percentage. Moreover, an increae in rubber content with an increase in thickness sees het U-value drop by -0.13 W/m^2K. Although no further increases in %rubber or thickness was made, by extrapolation results indicate that the U-value would decrease further. An increase in mass would evidently increase its embodied energy and its cost given the greater mass per unit volume ratio. Such results can only be obtained through further studies or prediction modelling.

CONCLUSION

Currently Maltese building construction norms are slow to adhere to building regulations, technical guidance document part F, even though it has become national law. Most of the traditional Maltese roof constructions never had insulation since their thermal mass, composed of composite limestone strata in different forms, did the job reasonably well. Admittedly comfort standards were also less sttingent than today, with older folk and farmers leading an outdoor life more than ever.

In warm climates where solar gains through flat roofs is a predominant heat source, roof insulation is a necessary requirement to reduce heat absorption into the building. This should reduce cooling loads particularly given the increase use of fossil-energy based HVAC systems. Based on this premise the use of the novel recycled rubber tiles reduces the overall U-value of the roofing element. Moreover, the benefit of using a material such as recycled rubber and inert waste, both with a high embodied energy content, means that there is also a lower demand for quarried limestone sand as a raw land-based resource. This is certainly one added value of using such tiles as insulation or as a complement to it to say the least. Waste rubber tyres are also shredded for re-use rather than dumped, taking precious voluminous space. So this is already a win-win scenario from a waste management perspective.

The objective of this paper was to create a new, thermally insulating roof tile made from recycled rubber as a replacement or complement to any insulating material. It can be laid on roofs and open terraces over habitable spaces, thus increasing the energy performance rating of buildings, particularly dwellings.

SCOPE FOR FURTHER RESEARCH

Parametric tests were performed to test the best percentage ratios in the mix design composition of the tile. From results obtained the newly designed tiles generally increase the thermal efficiency of the building. By increasing the thickness and also the rubber content of the tiles, the average range of U-values obtained scaled from 1.85 to 1.22 W/m^2K. This is still higher then the minimum requirement for thermal transmittance allowed ofr roof structures in Malta, that is, 0.59 W/m^2K (Technical Guidance Document, Part F, of the Building Regulations of Malta).

Although results are already promising, unless a very thick tile is used one would not achieve sufficient reductions in thermal transmittance therefore testing the tile further is recommended with the addition of complementary insulation. More work also needs to be done on varying the basic parameters, namely the design mix of rubber to sand ratio, beyond 60%, as well as the thickness of a tile over 90mm. Another area to be delved into is the aerated concrete itself, where a greaeter porosity brings with it a greater insulating property; hence modifications to the design mix can be tested. Different types of rubber as well as its granulated size (larger granules to pulverised) is also worth investigating. Moreover, the tile's abrasive resistance, inherent durability, and its resistance to moisture are among a few other areas within the scope for further research.

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Design Interventions to Encourage Pro-Environmental Behavior:

An Action Research Study on Waste Diversion in a University Residence Hall

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ABSTRACT

This action research study examined the effectiveness of four design interventions, which aimed to encourage students to recycle and compost in a university residence hall. The study took place at a major university in the United States, where recent efforts have been made toward a "zero waste campus". Zero waste is defined as diverting more than 90% of waste from landfill. In 2011, The Ohio State University successfully implemented a zero waste program in their football stadium and now plans to convert the entire campus to zero waste by 2030. Implementing zero waste across campus, however, proves challenging—especially in residence halls as they require a more complex logistical infrastructure and rely heavily on students' knowledge, attitudes, and practices. Using approaches from social practice design and anthropology, this study examined practical and scalable interventions with the ultimate goal of assisting in the future transition to zero waste. On a larger scale, these results may provide new knowledge in comprehensive waste management and methods of social practice design that encourage pro-environmental behavior change.

INTRODUCTION

Comprehensive solid waste management is a major challenge to sustainability. The practice of recycling diverts materials from landfill, reduces pollution, saves raw materials and conserves energy. Still, inconveniences of recycling and engrained social practices lead to minimal participation in recycling and composting programs—only 34 percent of America's waste was recovered in 2012 [1]. Academic institutions have begun to realize their environmental obligations to promote sustainable behavior among students, faculty, and staff [2, 3]. Zero waste is an emerging goal of sustainable materials management, where 90% or more of solid waste is diverted from landfills. To assist in recent efforts towards a "zero waste campus," this action research study explored the decision-making process associated with recycling on campus and examined the effectiveness of four design interventions encouraging students to recycle and compost in a university residence hall.

CONTEXT

The study took place at a major university in the United States, where recent efforts have been made toward a "zero waste campus". Achieving zero waste requires a shift from a *waste* management mindset to a *resource* management mindset where technical and biological nutrients are treated separately and have productive destinations [4, 5]. Zero waste plans are comprehensive and require diversion and aversion efforts including: material capturing, waste stream modification, and waste

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prevention. While waste stream modification and waste prevention are ongoing, material capturing can be improved through proper sorting practices.

In recent years, The Ohio State University (Ohio State) has made great strides in zero waste. In 2011, the Office of Sustainability started a zero waste program in their football stadium—one of the largest in the country. The stadium frequently holds over 105,000 fans and on average accumulates 8-10 tons of waste per game [6]. By 2013, the program was successful in diverting over 98% of waste—an average of 8 tons per game! Control over the material stream, cooperation from fans, and the ability to sort on the back end were critical components to the project's success [7].

After achieving zero waste in the football stadium, Ohio State set an ambitious goal to transition their entire campus to zero waste by 2030. This goal was articulated in 2008, and in 2013—five years later—the campus was still only capturing 31% of their waste (Fig.1)[8]. To determine how much of their waste had the potential to be captured, Ohio State completed a comprehensive waste audit in 2013. The audit found that 89.1% had the potential of being recycled or composted (Fig. 1). In other words, Ohio State has the ability to increase their current diversion rate of 31% to their potential diversion rate of 89% by improving sorting practices. This shift to zero waste not only involves structural changes in how waste is collected and processed, but also behavioral changes for members of the institution [9].

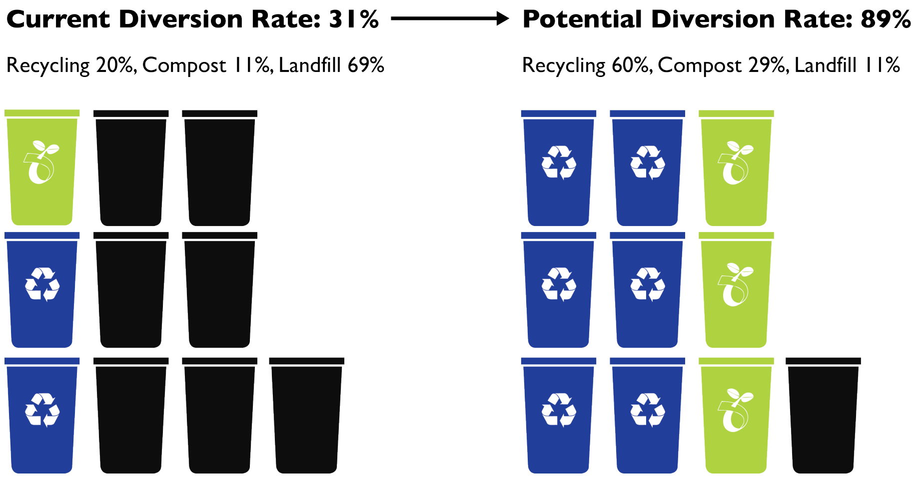


Figure 1: Current Diversion Rate (31%) compared to Potential Diversion Rate (89%), 2013

APPROACH

Interventions that promote recycling are not new, but these strategies typically address recycling as planned behavior that is guided by a rational decision-making process. Many decisions made throughout the day, however, are not rational. In terms of decision-making, people are governed by two systems of thinking: the automatic system guided by intuition, and the reflective system controlled by rational thought [10]. With a limited capacity for rational thought, many decisions turn to the automatic system where the least amount of *thinking* occurs. Months of observations across campus suggest that recycling is often one of these automatic decisions. As a result, the way recycling choices are presented can greatly influence the choice that is made [10]. On campus, throwing waste in the trash currently requires the least amount of thinking, in other words *trash is automatic* and as a result *many people do not recycle*. The intervention strategies in this study targetted the automatic system and the reflective system to determine what factors most influenced students' recycling practices. All interventions targetted the automatic system by sharing a new infrastructure where *recycling and compost became automatic*. Incrementally higher-level interventions targetted the reflective system by introducing education, eco-feedback, and social influence. This study used approaches from social practice design and anthropology and was completed in four iterative phases: ethnography, intervention design, intervention experiment, and analysis.

Ethnography

The research team used a grounded theory approach to observe recycling behavior and ask students why they recycle or not. The goal was to identify students' knowledge, attitudes, and practices in regards to recycling in order to develop a theory of student decision-making. Observations and interviews took place in the participating residence hall and the main dining facility.

Students admit that they typically choose the easiest way to dispose of their waste. Many students even throw things "away" subconsciously. They often choose the nearest bin out of convenience and rarely go out of their way to recycle. Some students will recycle more obvious items such as bottles and cans, but many students throw everything in the trash because they do not have to think about *what can be* recycled. Some students fail to recycle because they feel their individual behavior does not make a significant environmental impact. And while there is some social pressure to keep an environment clean by not littering, students feel little social pressure to recycle. These findings became the theoretical framework that guided the strategy and development of the design interventions.

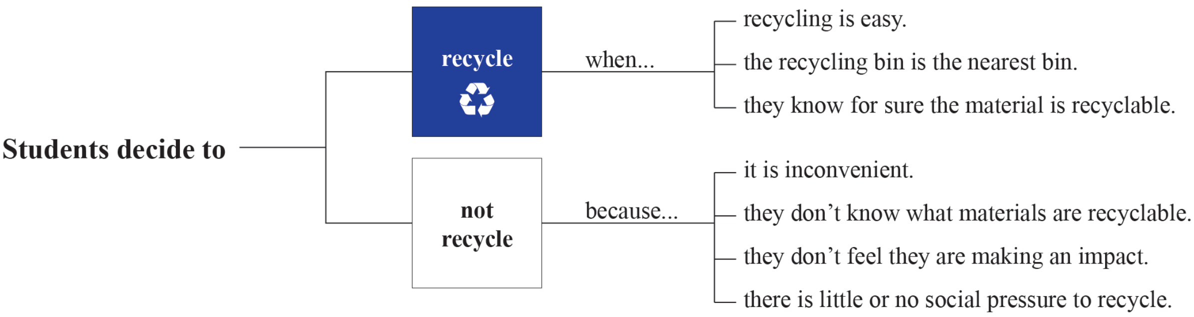


Figure 2: Emerging theory of students' decision-making process in regards to recycling

Intervention Design

Prior to the intervention experiment, the participating residence hall provided students with 2 large trash bins that were picked up by housekeeping daily (one in the bathroom and one in the common living room). If students wanted to recycle, they were given a small recycle bin and it became the students' responsibility to collect recycling and empty the bin. Students had to find a location for their bin, decipher what could be recycled, collect recycling, and empty on a regular basis—a much more laborious activity (mentally and physically) than throwing waste in the trash.

The emerging theory of decision-making suggested that students will recycle if it is easy, accessible, and they know what is recyclable—in other words they will recycle if it *becomes automatic*. On the other hand, students may not recycle if they have a limited understanding of their environmental impact, or a lack of social pressure. So, are clear instructions and an easy/accessible system enough to achieve zero waste in residence halls? Or do education and/or social pressure lead to higher diversion rates? The four interventions were designed to answer these questions. Interventions were incremental. That is, each intervention had increased involvement with students and thus, built in complexity. Design interventions 1–4 had the same baseline zero waste infrastructure and instructional signage. While, interventions 2, 3, and 4 built in complexity with increasing levels of environmental messaging and social pressure. The hypothesis was that higher-level interventions would have more influence on students' compliance with the zero waste program.

The interventions were implemented as follows:

Intervention 1: New Waste Collection Infrastructure. The previous system made trash disposal very easy and recycling more difficult. In this new system (Fig. 3), the trash bin in the common room was converted to *recycling* and the trash bin in the bathroom was converted to *compost*. A small *landfill* bin was added to the bathroom for personal hygiene waste. The housekeeping staff emptied all three bins daily. Both the compost and recycle bins were accompanied by a simple instructional poster.

Figure 3: Recycling, compost, and landfill bins with instructional signage

Intervention 2: Education. To further eliminate confusion about recycling and composting, intervention 2 utilized educational posters to provide general information about questionable materials (Fig. 4). These posters showed the environmental impact of recyclable and compostable materials and encouraged students to reuse and reduce. Posters were placed on the bathroom stall doors.

Figure 4: Informational posters

Intervention 3: Eco-feedback. To help students reflect on the impact their everyday practices had on their community and the environment, intervention 3 utilized social media to educate students on their behavioral impact, and suggest ways to make an even greater impact. Digital white boards were also placed beside the resident advisor's (RA) room to allow students to ask questions and offer feedback. This gave students an opportunity to get involved in the conversation.

Intervention 4: Social Influence. To create a sense of peer-pressure, students volunteered to be *Zero Waste Agents* who made sure their suitemates complied with the new zero waste system. Casually but consistently the behavior and attitude of the Zero Waste Agents set examples for pro-environmental behavior.

Intervention Experiment

The participating residence hall consisted of eight floors and approximately 400 students. There were two floors and approximately 100 students per intervention. During the 30-day intervention experiment, a new logistical infrastructure was implemented (Fig. 5) where the housekeeping staff collected one large recycle bin, one large compost bin, and a small landfill bin daily. In addition to the new infrastructure (easy access and clear instructions), three higher-level design interventions were evaluated.

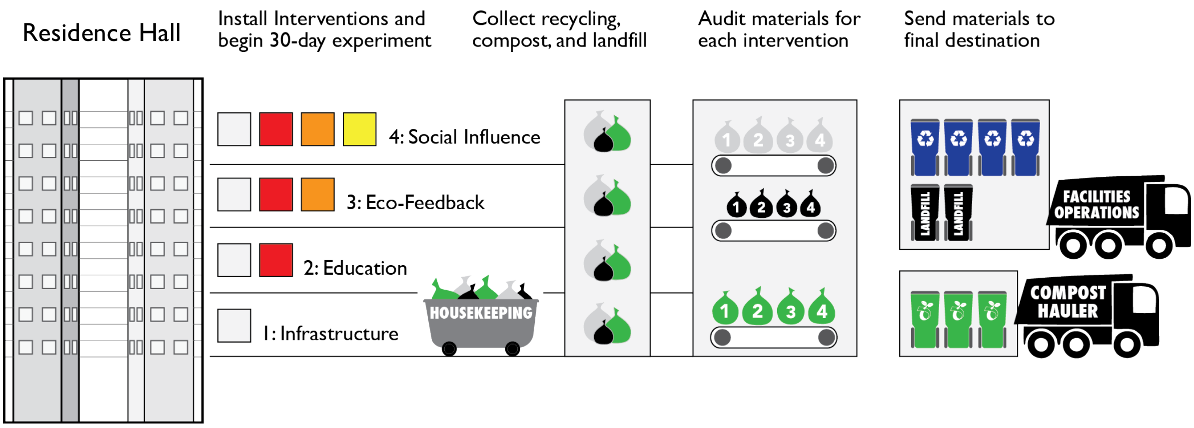


Figure 5: Logistics of waste collection during the 30-day intervention experiment

Analysis

The intervention effectiveness was measured and analyzed in two ways: (1) changes in practices—measured by overall waste diversion and accuracy of sorting, and (2) changes in perceptions—measured by reported knowledge, attitudes, and practices. Professional waste audits and weekly visual assessments were recorded to determine diversion rates and sorting accuracy. Questionnaires were administered before and after the interventions to assess changes in perceptions. 101 students (43 women and 59 men) responded to the pre-experiment survey and 26 students (16 women and 10 men) responded to the post-experiment survey. Data was analyzed for each individual intervention and all interventions as a whole.

FINDINGS

Changes in Practices

During the program, students sent an average of 71% of their waste to be recycled and composted, a significant increase compared to the 31% campus average in 2013. Figure 6 shows the waste distribution before the experiment (campus average), during the experiment (in a single residence hall), and the goal to achieve zero waste in 2030. The results show a significant step towards zero waste residence halls in a very short period of time.

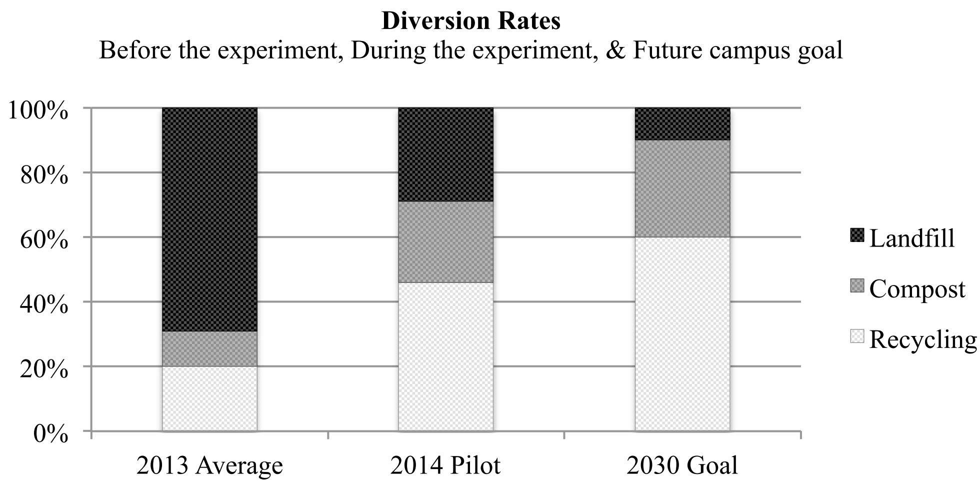
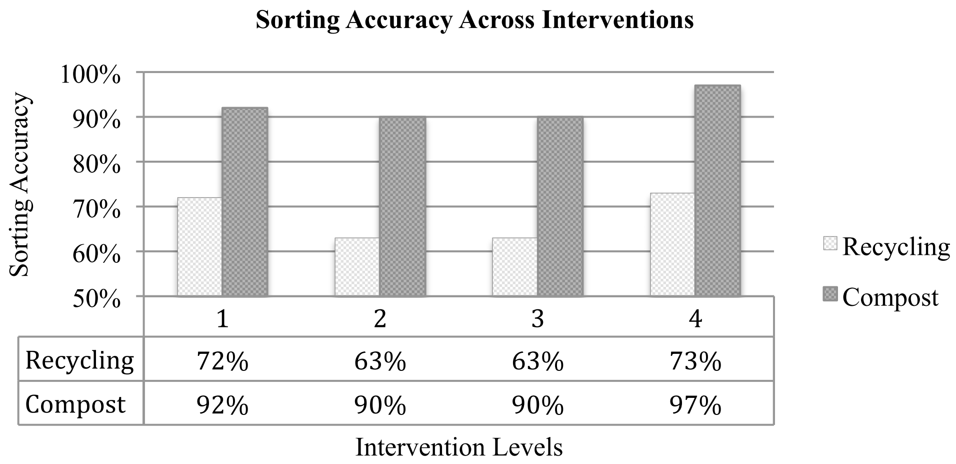


Figure 6: Results of experiment in comparison with campus average and campus goal

Comparatively, the four interventions showed no significant difference in the amount of waste diverted, however, there was a significant difference in the accuracy of sorting (Fig. 7). The baseline intervention achieved 82% overall sorting accuracy. The highest-level intervention—using *Social Influence*—achieved 85% sorting accuracy, but showed no statistical difference from the baseline intervention. The second and third level interventions, however, both achieved 76% sorting accuracy and showed a statistically significant (and surprising) decrease of 6% from the baseline intervention. In addition to differences between interventions, across the board, sorting accuracy of recycling (62% average) was significantly lower than sorting accuracy of compost (92% average).



	1	2	3	4
Recycling	72%	63%	63%	73%
Compost	92%	90%	90%	97%

Figure 7: Results of sorting accuracy for each intervention

Changes in Perceptions

As a whole, students' perceptions about recycling and composting changed significantly after experiencing the design interventions (Fig. 8). In general, students reportedly had a better understanding of how to recycle properly and tried harder to comply. After the experiment, they found recycling more rewarding and felt more strongly that it could positively impact their community and the environment. Students also felt more optimistic that by recycling they could motivate others to recycle. Comparing pre and post surveys, students in intervention groups 1&4 reportedly tried harder during the experiment, while students in intervention groups 2&3 showed no significant change in their effort.

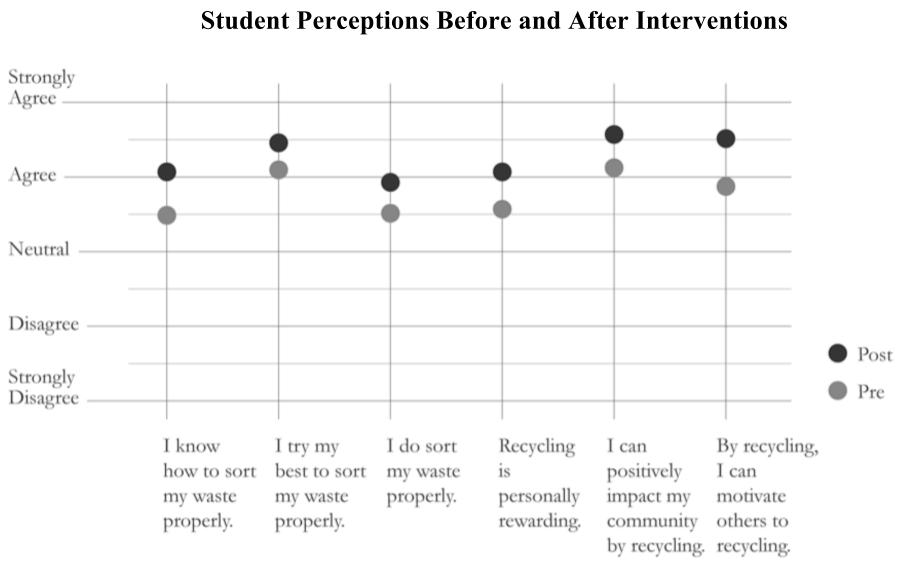


Figure 8: Changes in students' perception before and after the intervention experiment

DISCUSSION

Overall, having large, accessible recycle bins that were picked up daily by housekeeping drastically increased (more than doubled) the amount of recyclables collected—although sorting accuracy could be improved. To increase sorting accuracy, the authors believe it would be beneficial to have the compost bin directly next to the recycle bin in the common room. Students typically ate in the common room, and the main recycling contaminant was food waste. In order to dispose of food waste properly, students had to walk to the compost bin in the bathroom. The primary reason for having compost in the bathroom was to easily dispose of paper towels. However, if paper towels could be eliminated or minimized, the compost bin could be next to the recycle bin, making it easier for students to dispose of their food waste.

When comparing intervention effectiveness, student participation did not increase with each level as hypothesized. However, students in intervention groups 1 and 4 reportedly tried harder and achieved greater success during the experiment. Why is this? What did intervention group 1 and 4 have in common? To find out, we interviewed students at the end of the study and asked why the baseline intervention might have done as well as the highest-level intervention. One of the *Zero Waste Agents* mentioned that the RAs on the floors assigned to intervention group 1 and 4 were highly involved with their residents. Although the RA involvement was not a controlled variable, it was certainly an unavoidable influence that could vary widely from floor to floor. It seems that peer influence was present on all floors (not just intervention 4) in the presence of an RA, and that some RAs are better than others at getting their students to participate in activities; in this case, the zero waste pilot program.

It is important to note the limitations of the study. First, the intervention experiment was implemented in the middle of the school year. Students were accustomed to the existing waste system, and compared to starting a system at the beginning of the year, they could have been more resistant to change. Second, the study did not include a waste audit of the participating residence hall prior to the intervention experiment. Therefore, an assumption was made that the material stream and recycling rates in the residence hall did not widely vary from the campus-wide stream. Observations made prior to the intervention experiments confirmed that students were recycling 25-30% of their waste, however these limited data points could not be used for statistical analysis.

CONCLUSIONS

How close to zero waste can we get with a simple and efficient infrastructure? Is education as important as we think when it comes to encouraging recycling behavior? What kind of influence does social influence have on student's recycling behavior? This study suggests that when people are faced with a choice, a large number will accept the default, the option that requires the user to do nothing [10]. A simple and efficient infrastructure can be a great start to achieving zero waste. And suprisingly, education may not be as important as we think, but social pressure can significantly influence students to recycle and compost.

In this study, a simple and efficient infrastructure was the foundation for a successful zero waste program. Many residence halls offered frequent pick-up of large trash (landfill) bins, but students took out recycling in small crates. Offering recycling and compost pickup made the recycling process easier and more accessible to students. In addition, appropriate bin size and bin placement were essential to the success of a zero waste program. In general, bin sizes should more accurately reflect a university's material stream (which Ohio State determined to be 60% recycling, 30% compost, and 10% landfill waste) and bins should be placed in the room where the majority of that material stream is accumulated. Students also need clear and simple instructions.

Beyond instructions, additional education about recycling, composting, and environmental impact had little impact on the greater success of this zero waste program. Students did, however, show an interest in having access to additional information online. Perhaps additional information could be shared through currently used social media channels (e.g. links to zero waste information on an existing residence hall homepage) accessible to those students with a desire to know more. Additional information that is available, but not invasive, may be the motivation some students need to become advocates for change.

Finally, social influences played a very influential part of students' daily recycling practices. This study addressed peer-to-peer relationships and authority figures as influencers of student perceptions and behavior. A peer influence, especially from a mentor who is relatable and respected, can significantly motivate students to participate in pro-environment behaviors such as recycling. While changing the default from trash to recycling through a simple zero waste infrastructure was the first step towards increasing diversion rates, behavioral reinforcement from recycling advocates, especially resident advisors, significantly increased compliance.

This study specifically targeted the residential population at a large university in the United States, however findings from the study revealed significant considerations for comprehensive waste management as well as design intervention strategies that encourage pro-environmental behavior. This study focused on waste management, but the findings can be applied to many institutional behavior change endeavors.

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Session PA : Cities and neighbourhood development

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Auditorium - Knowledge Consortium of Gujarat

A Study on Micro-climate of URBAN CANYON and Its Impact on Surrounding Urban Area

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ABSTRACT

Thermal comfort in outdoor settings is a topic that, until recently, has received little research attention. Previous studies have shown that thermal comfort is the main component of comfortability in an urban open space. A stretch of major road surrounded by mixed development in Dhaka city was selected as the study area. The goal of this research was evaluation of effect of urban canyon on surrounding microclimate. Data from ENVI-met simulation were compared to field survey data to understand the dynamics of mean temperature (MT), mean radiant temperature (MRT), relative humidity (RH) and wind speed from 9am to 7pm in the selected urban canyon. The result of this research shows canyon microclimate penetrated 75 to 100 meters deep into the branch roads. The effect of penetration increased with increasing width of the canyon. Green and open spaces around the canyon had impact on reducing temperature as well as penetration. Wind speed and relative humidity depends on road pattern, orientation and build environment characteristics of surrounding urban area. The results of this study can be helpful in defining architectural guidelines for typical urban canyon surrounded by mixed development in densely populated cities similar to Dhaka.

INTRODUCTION

Many cities in South Asia are currently undergoing rapid urbanization. This is causing changes in land use, urban form, and ground cover. However, the planning and design issues related to climate are not properly considered. Size of the city, orientation and width of streets, density of the built-up area, height of the buildings, and the presence of green areas and open spaces are important elements that affect the urban microclimate. Only In the last 20 years the transfer of knowledge from climatologic and biometeorologic studies to urban & architectural design tools has begun to take place [(i)].Dhaka is a densely built tropical city with unplanned road network. Improper ratios of primary and secondary road create a unique urban canyon scenario which also characterized by highly dense built area and less open spaces. This canyon or adjacent branch roads can be converted to urban outdoor activity spaces if thermal comfort is ensured. Air temperature mean radiant temperature, relative humidity and wind speed are the environmental parameters that primarily affect thermal comfort of a human being. In urban areas, the great variety of different surfaces and sheltering obstacles produces a pattern of distinct microclimate. To simulate these local effects, micro scale surface– plant–air interaction schemes with a special extension to typical artificial urban boundaries are required.

OBJECTIVES OF THIS STUDY

- To explore the nature of major urban canyon and its effect on urban micro climate.
- To identify the intensity of urban canyon effects penetrated in surrounding build area.
- To prepare a basis for further study to investigate the consequences of urban canyon effects.

AREA OF STUDY

Dhaka city is located at 23.24°N, 90.23°E, and 8.8 m above sea level. A stretch of 25m wide road of Begum Rokeya Avenue, Dhaka was chosen for this study. For survey, an area of 500m X 230m was taken along the road which is 14^0 inclined with North-South axis. Neighborhood buildings are one to nine stories high. Secondary road width varies from 3m to 7.5m. North-East part of the study area is highly dense with buildings, mostly 6 to 9 stories. South-East part has low rise buildings, mostly one to two stories. South-West part consist of many open and green spaces and low rise buildings. An indoor stadium is situated at North-West side which stands on a large landscape. Footpath and road of West side has lots of trees whereas, the East side is faced with buildings. Island of this road has 2m high plants. Data has been taken at different selected points of the footpath, road and island as field measurements and simulation was studied at road level to understand and compare micro climatic situation at different time of the day.

Figure 1 *Areal view of study area (1) west & east side footpath of main canyon (2&3) branch road (4)*

METHODOLOGY

A field measurement of mean Temperature (T), relative humidity (RH) and mean radiant temperature (MRT) was conducted with humidity/temperature meter (LUTRON HT-306) in study area at 3:00pm. All measurements were taken at 1.8m height to observe human comfort in urban canyon. Data readings were taken at footpath, road and island at both East side and West side of the canyon. The survey output was then plotted and analyzed. A computer simulation was carried out in ENVI-met by using weather data of Dhaka city on that particularly day. Simulation of the parameters was done for 9:00am, 11:00am, 1:00pm, 3:00pm, and 5:00: pm and 7:00pm at the height of 1.8m to understand the micro climate at different times of the day.

Simulation with ENVI-met V3.0

ENVI-met is three dimensional microclimate modeling software for simulating the surface, plant, air interactions in urban environment with a typical resolution of 0.5 to 54 m in space and 10 sec in time. ENVI-met uses a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics (ii). ENVI-met outputs binary files which have to be imported into the visualization program LEONARDO, a graphical interface for displaying and analyzing numerical data. The output file displays the data with color coding.

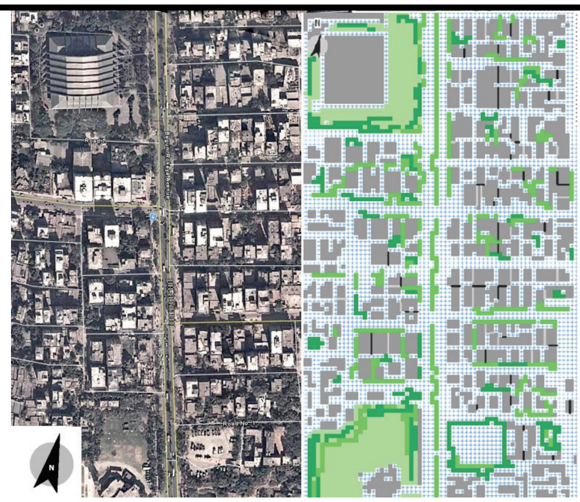
Simulation period was from 9:00am to 7:00pm of September 4, 2013. Study area of around 230m×500m×54m was transformed in the ENVI-met model grid with the dimension 57.4 µm, 125 µm and 18 µm respectively. This resulted in 34 grids with a resolution of 4µm×4µm×3µm for the study area.

ENVI-MET CONFIGURATION

The ENVI-met configuration file (.cf) was created using the environmental readings listed in Table 1.

Table 1: ENVI-met Configuration information for simulation and the model file

Sl	Simulation parameters	Values
1	Start Simulation at Time (HH:MM:SS)	09:00
2	Total Simulation Time in Hours	10:00
3	Save Model State each	120
4	Wind Speed in 10 m ab. Ground [m/s]	3
5	Wind Direction (0:N.90:E.180:S.270:W..)	180
6	Roughness Length z0 at Reference Point	0.1
7	Initial Temperature Atmosphere [K]	293
8	Specific Humidity in 2500 m [g Water/kg air]	7
9	Relative Humidity in 2m [%]	72



RESULTS AND ANALYSIS

The field survey readings from the study area are tabulated in Table 2. The potential reading for climate components of the same study area done at the same time points of the same day were deducted from simulation through ENVI-met. The simulation readings are tabulated in Table 3. Figures 2 to 5 show the simulation results.

At 9:00 am, Canyon is moderate cool with medium humidity and high wind speed. East side of the canyon is warmer than west side. Canyon beside green space is cooler than building sides. Urban open space, green area and low rise low density built area have more humidity and lower MRT than canyon. Tunnel effect created around branch road connecting points.

From 11:00 am to 3:00pm, Canyon is heated up and humidity level decreased along with wind speed. Branch roads on east west direction are cooler where secondary roads parallel to main canyon at N-S direction is warming up.

From both simulation study and field study, it was found that around 1:00 pm heat of the canyon is partially (35m to 76m) permeate to the branch roads on east direction. Secondary roads parallel to the main canyon also heated like this and have some similar heat permeation. Overall MRT increased and humidity decreased specially in secondary branch roads. Presence of tree cause noticeable lower MRT in some part of road's island and footpath. Trapped heat of urban canyon permeated to surrounding build area through branch roads. Trees and Green areas decreased this permeation rate. At 3:00 pm, west side branch roads began to affect by canyon heat permeation because of direct solar radiation. All spaces have high MRT. Wind shadow created at East - West oriented branch roads.

After 5:00 pm, canyon and surrounding area start losing temperature and gaining humidity. Green areas lose temperature at higher rate .Wider part of the canyon affects more. It is found that green areas cool down more quickly rather than build area.

***Figure 2** Potential Mean Temperature Simulation Result from 9:00 AM to 7:00 pm*

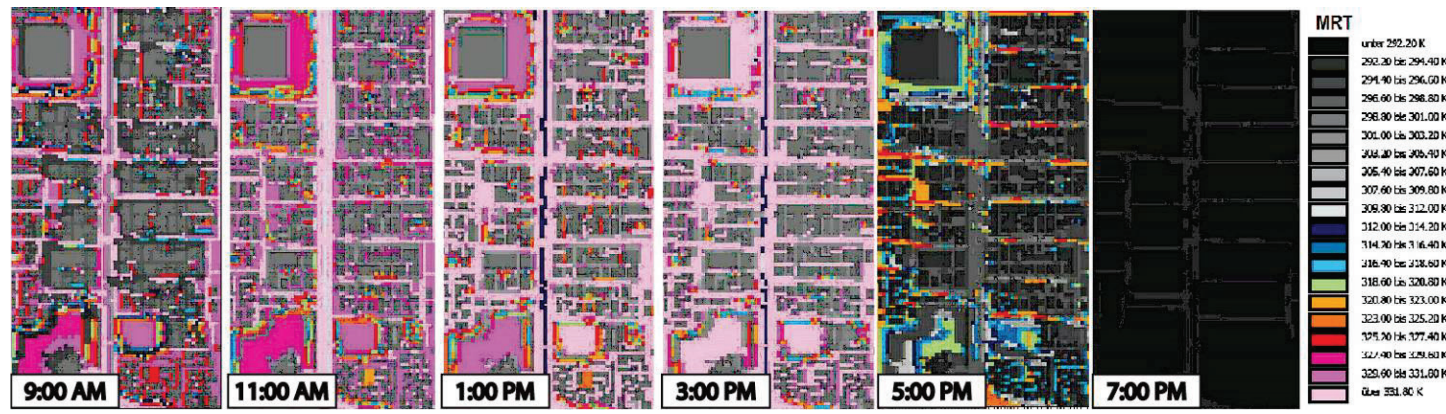


***Figure 3** Potential Mean Radiant Temperature Simulation Result from 9:00 AM to 7:00 pm*

Table 2: Field data readings from the study area at different times of the same day

Data point	East side foothpath			East side road			Island			West side road			West side foothpath			Data points map
	Temp. (°K)	RH (%)	MRT (°K)	Temp. (°K)	RH (%)	MRT (°K)	Temp. (°K)	RH (%)	MRT (°K)	Temp. (°K)	RH (%)	MRT (°K)	Temp. (°K)	RH (%)	MRT (°K)	
A	308.32	63.61	308.3	310.92	57.23	313.48	311.79	54.07	313.31	309.79	55.28	311.39	308.09	65.07	308.83	
B	309.34	60.12	308.18	310.18	59.39	310.53	310.06	59.39	310.81	308.77	61.77	308.7	308.33	65.99	308.81	
C	308.24	64.4	308.59	307.89	64.88	307.74	307.21	66.85	307.6	306.61	68.24	307.52	307.35	65.84	307.19	
D	308.31	64.29	308.45	308.05	65	307.99	307.94	65.58	308.1	307.81	65.95	307.83	308.39	63.91	308.02	
E	307.89	64.11	307.9	308.07	63.91	308.66	307.9	65.45	308.31	307.43	66.23	307.63	307.74	64.91	307.69	
F	307.79	64.31	308.77	308.17	64.21	308.69	309.51	61.35	309.5	308.23	63.66	308.22	308.04	65.05	308.2	
G	309.56	60.75	310.23	308.61	63.08	308.2	307.61	65.07	307.77	307.53	65.96	307.54	307.54	66.11	307.61	
H	308.47	63.39	307.91	308.11	65.67	307.89	307.99	65.41	308.19	308.99	65.38	308.35	307.76	65.95	307.74	
I	310.13	59.18	310.14	309.56	61.48	308.37	308.08	65.72	308.37	307.31	67.6	307.24	307.06	69	307.27	

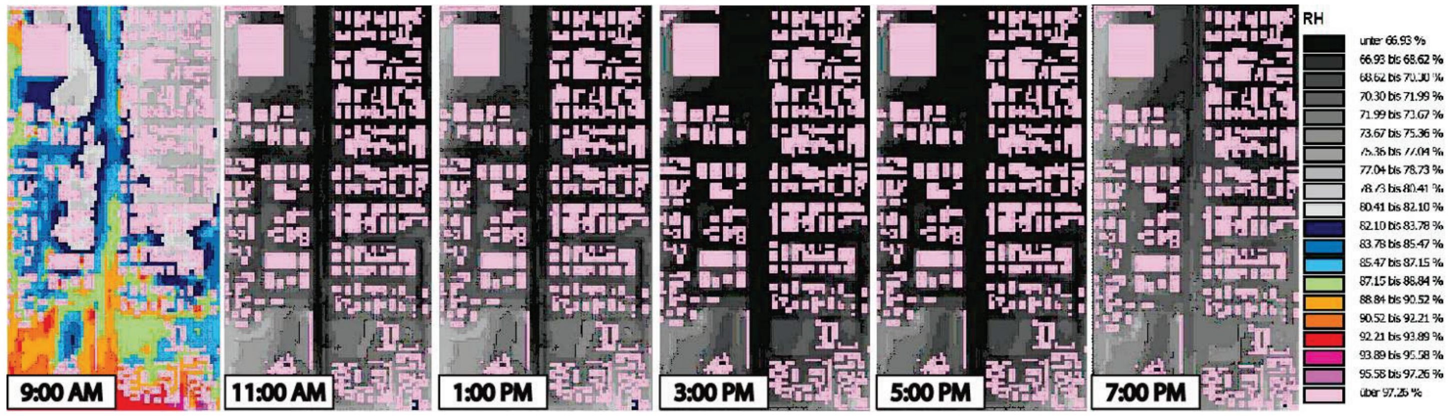


Figure 4 *Potential Relative Humidity Simulation Result from 9:00 AM to 7:00 pm*

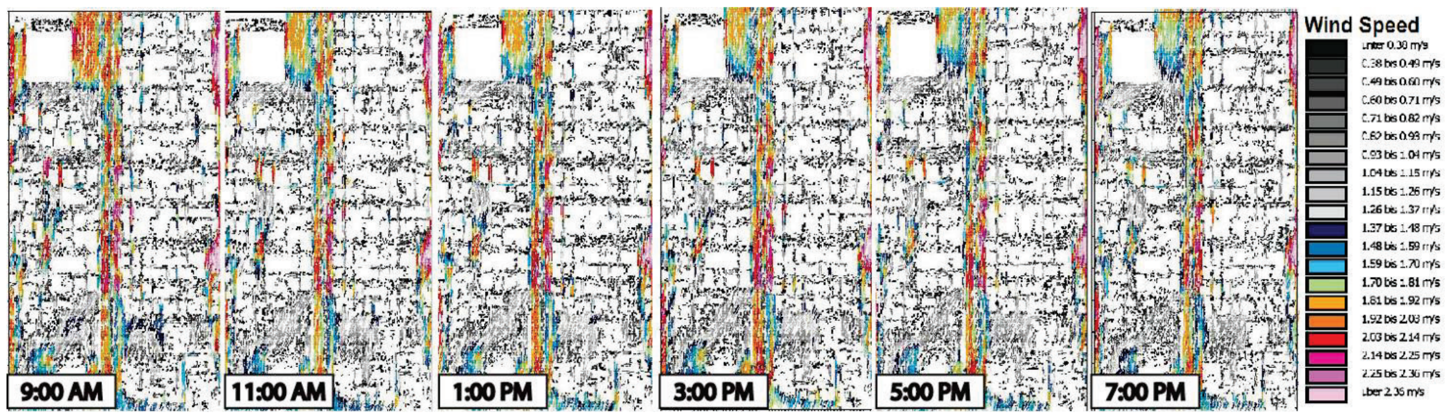


Figure 5 *Potential Wind Speed Simulation Result from 9:00 AM to 7:00 Pm*

At 7:00 pm, Build area trapped more heat rather than major urban canyon. Overall RH increased maintaining same ratio. MRT at secondary roads are higher than main canyon. MRT at urban open space, green area and low rise low density, high density built area is lower than canyon. It is found that heat trapped down inside build area. RH improves with decrease of temperature. Branch road and canyon contain some MRT for long time.

Table 3. ENVI-met simulation result of canyon at study area

Time	Pot. Temperature(ºK)	Relative Humidity (%)	Mean Radiant Temp (ºK)	Wind Speed (m/s)
9:00 am	297.00 to 297.70	84.85 to 91.17	332.31 to 337.11	1.31 to 2.35
11:00 am	302.63 to 303.67	65.73 to 73.05	337.11 and above	0.78 to 2.25
1:00 pm	303.88 to 305.12	61.67 to 65.45	339.51 and above	1.15 to 2.35
3:00 pm	303.84 to 304.5	62.87 to 66.50	338.13 and above	1.04 to 2.25
5:00 pm	301.54 to 301.88	67.06 to 73.60	303.56 to 322.73	0.93 to 2.25
7:00 pm	299.02 to 300.00	70.17 to 73.46	292.61 to 293.13k	0.78 to 2.14

FINDINGS AND DISCUSSION

(1) It was observed that environmental effects of canyon microclimate permeate to surrounding built-up area depending on characteristics of built environment and road pattern. This can be increased by additional solar penetration and width of branch roads. Row of trees at footpath reduced the effect of heat permeation from urban canyon.

To reduce permeation of canyon's thermal effect, connected branch roads should not align with solar direction. North – south aligned branch roads may contain less MRT, more shadow and RH to ensure better thermal comfort. Proper landscaping can improve thermal comfort of canyon as well as reduce permeation to surrounding built-up area. Medium high trees which provide better shadow at footpath should place along with junction of footpath and road. Large trees which act as better barrier against permeation should place at other side of footpath. Shrubs and low high plantation have less impact on overall canyon microclimate.

(2) Heat permeation increase with branch roads width.

Narrow branch roads may restrict traffic, but has better thermal comfort. Designers may consider separate traffic system to convert narrow branch roads into live and comfortable urban interaction spaces for pedestrians.

(3) Adjacent Open and green area had comparatively low temperature (2-3K) and wind velocity with higher RH than the canyon.

Idea of connect green open space to the canyon can be an effective way to control canyon's microclimate. It significantly reduces heat built-up at canyon as well as provides refreshment to the pedestrians.

(4) Urban canyons heated up and cooled down more quickly than the surroundings. The impact of MRT lasted for a while in canyon but comparatively longer in narrow branch roads. Plantation at road dividers effectively reduced MRT.

Trapped thermal condition of narrow branch roads can be considered at designing urban outdoor spaces. Branch road's orientation, placement and character should design with consideration of solar position in different seasons to provide comfortable outdoor spaces throughout the year. Selection of trees at road dividers can play a vital role to shape up canyon's microclimate in different seasons.

(5) Wind velocity was higher where urban canyon and branch roads were oriented with gradient wind flow. Road junctions often created tunnel effect where dense built-up areas remained in wind shadow.

Intelligent placement of small pocket spaces in dense built-up area considering tunnel effect and wind direction can be interesting. Before design build area, designer should have consideration of gradient windflaw pattern of the particular area as well as future prediction of wind map to reduce wind shadow zone.

SCOPE AND LIMITATIONS

This analysis specially focused on the impact of urban canyon on the micro-climate of the surrounding area on an urban canyon. Similar study can be done on other types of urban canyon in term of orientation, size and build area pattern.

In this research, field data varies from simulation result 5 to10%. The tools to create the urban environment in ENVI-met are limited to buildings, soils/pavement materials and trees/vegetation. It was not possible to add the thermal heat capacity of the building materials; but only a single constant indoor temperature.

ACKNOWLEDGMENTS

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Study on the Sustainable Renewal of Poor Rural Communities of Southwest China

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ABSTRACT

Cities and counties in China experience unbalanced development as well as vulnerable economies and environments despite the rapid country-level progress. These poor villages thus face the enormous challenge of sustainable development. The government's attempt of improving the situation through its "urban–rural integration" policy to promote the development of rural areas has helped achieve short-term objectives in building construction and some other aspects. However, this policy is a disaster for long-term development in rural areas. Specifically, only 5% of the rural areas in Southwest China, especially those located near cities, are suitable to the government's policy; the remaining 95% of villages, especially those in remote areas, need to find their own ways to realize sustainable development.

This study combines the theories of sustainable development in China and other countries and proposes the use of the "endogenous development" concept to meet the development needs of poor rural areas. Under this model, the villagers can use the modified "traditional ways" to improve their housing conditions (i.e., space, materials, daylighting, and ventilation), public health circumstances, and financial and cultural situations. This study tests the theory using two case studies of the Yangliu and Ma'anqiao reconstruction projects and provides strategies for the sustainable renewal of poor rural areas of Southwest China.

Keywords: *sustainable renewal, Endogenous development, poor rural communities, Southwest China*

1. INTRODUCTION

The Chinese government invests in and provides preferential policies for rural areas. However, several of these policies are unsuitable for Southwest China, a multi-ethnic area with a considerably diverse and complex natural environment, which remains undeveloped despite the country's rapid development. This study combines the sustainable development theories in China and other countries to introduce the concept of "endogenous development" that could solve the problem. The study likewise establishes a sustainable development framework for poor rural areas in Southwest China.

2. BACKGROUND AND PROBLEMS

The scope of the study includes Sichuan, Yunnan, Guizhou, and Chongqing in Southwest China (Figure 1). These four provinces have a total land area of 1,134,400 square kilometers (Wan, 2013). Southwest China is home to ethnic groups and minority nationalities, many of whom have a low educational level. This mountainous area with complex topography and bad transportation is frequented by natural disasters; such characteristics seriously impede the development of both its society and its economy.

2.1 Poverty Problems

The mountainous Southwest China has inconvenient transportation and low land-use efficiency. Its productivity level is relatively backward, and its agricultural structure is unbalanced. The villagers lack the ability to abandon the traditional agricultural model. Therefore, an increasing number of villagers go to large cities to seek jobs to feed their families; this phenomenon has caused villages to become empty and lifeless. The per capita net income of rural households of Southwest China is less than the average level of China (Figure 2).

Figure 1: the scope of Southwest China

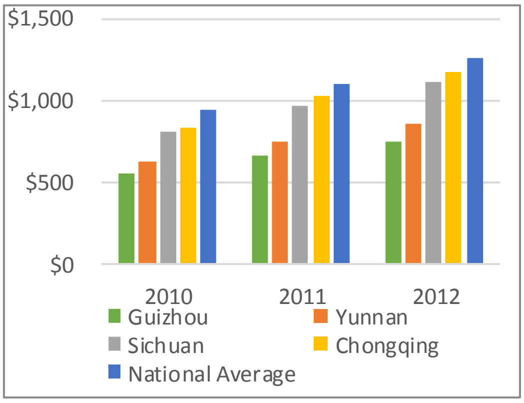

Figure 2: Per capita net income of rural households by region in China

2.2 Environmental Problems

Villagers cannot determine an appropriate method for waste management in poor rural areas because of deficient knowledge on public health. As a result, solid and liquid wastes pollute land and water resources. The so-called solid white waste pollutes both soil and water. Non-treated waste can produce toxic substances that attend to the top of the food chain. This environmental problem seriously damages the liver and the nervous system of humans (Zhang & Yu, 2007).

2.3 Public Health Problems

Lack of consideration for health issues is a common problem across the poor rural areas in Southwest China. Villagers do not fully understand the importance of health, and this situation adversely affects people's health and lives. For instance, burning firewood is the principal source of indoor air pollution; high indoor levels of PM10 in rural areas lead to several diseases, such as upper respiratory tract infection and asthma (Guo, 2005). Moreover, dry latrines that are extensively used in poor rural areas typically cause infectious diseases and zoonoses (Hu, 2009).

2.4 Building Renewal Problems

Various architectural forms follow unique regional conditions, such as those in the rural areas of Southwest China. However, traditional architecture lacks systematic ecological strategies and has technical problems with regard to anti-seismic design. At present, rural communities lack proper infrastructure and public service facilities; therefore, a suitable strategy for building renewal must be developed by comprehensively considering community planning and building design.

2.5 Government Policy Problems

Several important policies for rural development have been implemented in China, such as the 11th Five-Year Plan, which puts forward new countryside construction in 2005, and the Third Plenary Session of the 18th Central Committee, which emphasizes urban–rural integration as the fundamental solution to rural issues in China. However, these policies insufficiently focus on poor rural areas with complex topography and deficient transportation and have thus failed to produce the desired effects.

3. A SUITABLE MODEL FOR RURAL DEVELOPMENT

Cities and counties of Southwest China have unbalanced development and extremely sensitive economic, environmental, and public health situations. Therefore, these areas face an enormous challenge in terms of sustainable development. The government has implemented the urban–rural policy to promote the development of rural areas and thus improve their situation. This policy is a means for officers to achieve the short-term objective in building construction and other aspects. However, this policy is a disaster for long-term development of rural areas because only 5% of villages, especially those counties near cities, are suitable for urban–rural integration; the remaining 95% of villages, especially those in remote areas, should determine their own means of realizing sustainable development (Qiu, 2007). Thus, endogenous development may be the appropriate model for poor rural areas in Southwest China.

Endogenous development entails "respect for the cultural identity, [wherein] people have the right to own their culture. . . . Humans are the power [and] also the purpose of development. In form, development should be generated internally; in purpose, development should serve the people" (Huang, 1988). Compared with the old rural development model, the theory of endogenous development is defined by three key points (Table 1): first, the shift in emphasis from inward investment to endogenous development, which promotes the development of resources found within the region instead of attracting investment from external sources; second, the shift in delivery mode for rural development from a top–down to a bottom–up approach; and third, the shift in the structure of rural development policy from sectoral modernization to a territory-based integrated rural development (Michael, 2011).

Table 1. Features of the modernization paradigm and the new rural development paradigm

Modernization	New rural development paradigm
Inward investment	Endogenous development
Top-down planning	Bottom-up innovation
Sectoral modernization	Territorially based integrated development
Financial capital	Social capital
Exploitation and control of nature	Sustainable development
Transport infrastructure	Information infrastructure
Production	Consumption
Industrialization	Small-scale niche industries

4. STRATEGIES FOR RENEWING POOR RURAL COMMUNITIES

Sustainability comprises three dimensions, namely, environment, economic, and social dimensions. Social sustainable development covers several issues, such as peace, security, social justice, and human settlement. A sustainable social environment focuses on health and education, and sustainable societies provide high levels of health and wellbeing to their members (Jeremy, 2003). The strategies for renewing poor rural communities are expounded in this paper from the social, environmental, and economic aspects according to the practical application.

4.1 Fully Respect the Autonomy of Villagers

In 2005, the Central Committee of the Communist Party officially launched the "construction of a new socialist countryside" policy as "a major historic task [that] relates to the Chinese modernization process in the future" (Xinhua News Agency, 2005). The local government has used unified management, as well as unified planning and designs, to merge smaller villages or to move them to another site. A "rural house standard atlas" was used for reference in building apartments, which were not easily changed according to the opinions and the difficult-to-meet needs of villagers. However, the endogenous development model suggests that designers actively listen to the villagers' viewpoint and follow their actual needs. Furthermore, in this model, the completed construction is evaluated through value orientation of villager groups. This approach provides an effective way to enhance public participation in architectural design and to improve the design quality of new residential communities.

4.2 Provide More Public Space

In the traditional development model, the local government prefers to support the construction of infrastructure, such as roads and bridges, and a “village center” serves as a venue for village leaders to hold their meetings. In endogenous development, more attention is paid to communication infrastructure than physical infrastructure. However, very few public spaces in most rural communities of Southwest China are available for interflow or for educating villagers of all ages.

4.3 Make Use of Local Material and Resource

In the pursuit of rapid economic development, the traditional development model often overlooks the effect of development on the environment. By contrast, endogenous development finds ways to increase the value of natural resources in rural areas through prescriptions. For instance, a regional climate analysis is conducted prior to the architectural design to find the most suitable passive design to minimize energy consumption of buildings. Local natural materials should be used during construction. Furthermore, construction wastes generated during the project should be recycled. Natural energy sources, such as solar energy and wind energy, are good alternatives to non-renewable energy sources. Architectural strategies that follow local conditions can reduce the negative effect of construction and development on the environment.

4.4 Develop Traditional Construction Techniques

Large-scale intensive house construction is difficult in poor rural areas with a complicated mountainous terrain. This terrain results in traffic inconvenience, which means that the transportation cost of industrial construction materials will be high. Meanwhile, low education level villagers are not easy to accept the specialized construction techniques. Traditional construction techniques have an irreplaceable regional advantage in rural areas. Thus, architects should investigate local traditional techniques and combine them with modern technology by using the “high science and low technology” concept for innovation and improvement, while preserving the technical mastery of the farmers.

4.5 Villagers Participation and Cooperative Construction

Local villagers are the main targets and movers of efforts toward the renewal of rural communities. During the period of house construction, villagers help each other by way of “labor exchange” and exert effort to build their own homes. Participation and cooperation enhance the cohesion of villagers; such relationship can be used as motivation for people to remain on their own lands and not fall for labor migration. On that basis, the semi-self-construction system and regional cooperatives were also established.

4.6 Proper Economic Strategies

The use of indigenous technology and local materials greatly reduces the purchasing and transportation costs in projects for the renewal of rural communities. The participation of the local workforce not only improves labor skills but also maximizes the value of labor because it encourages “labor exchange” and “volunteer work.” Therefore, local resources are effectively utilized by the most appropriate configuration in this region.

4.7 Environment-Friendly Strategies

The effect of the rural community development process on the environment should be reduced. Household wastes and those generated from production should be properly classified, and small-scale landfills should be available for the disposal of such garbage. Sewage needs treatment before being discharged to rivers so that the water could be fit for everyday household use after sedimentation and purification processes. These strategies will help improve the ecological carrying capacity of the environment.

4.8 Public Health Strategies

Implementing ecological toilets and separating livestock are important aspects of public health strategies. In Southwest China, animals and humans share very limited land, especially in residential areas, because of economic and land conditions. By optimizing the residential design, rational space can be designed to separate animals from humans in rural communities. In addition, the establishment of eco-toilets will eliminate the "dirty and messy" status of traditional toilets and will significantly improve public health. People's awareness of public health could also be enhanced by the promotion and popularization of related knowledge.

Generally speaking, the sustainable renewal of poor rural communities of Southwest China could follow the below steps:

1. Before the start of the design process, local climate, culture, and traditional techniques should be analyzed systematically.

2. During the design period, the practical needs of the villagers should be considered. Local materials and resource should be used, and traditional techniques should be improved by the "high science and low technology" concept.

3. During the construction period, villagers should participate and learn the modified techniques, which will be the ways to make their living.

4. After the construction period, the modified techniques and the renewal model should be publicized and promoted to improve the endogenous development of these areas.

5. CASE STUDY

5.1 RECONSTRUCTION OF YANGLIU VILLAGE

Yangliu Village has suffered a major geological damage in the 5/12 Wenchuan earthquake in 2008 when more than 85% of the rural houses were damaged. To avoid further geological damage, the village government decided to relocate the entire village to an open area near the Minjiang River. Architect Hsieh Ying-chun and his team carried out the overall planning and architectural design for the new site based on traditional customs and lifestyle. The construction work was successfully completed with good use of "collaborative construction" (Figure 3) and sustainable ecological strategies. The cost of per square meter is less than brick-concrete building in the same region (Figure 4).

Figure 3: collaborative construction

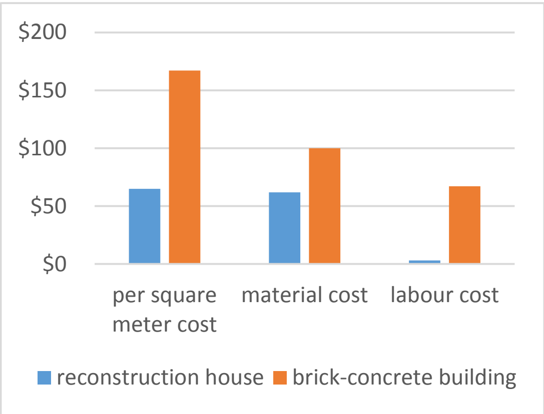

Figure 4: cost comparison of reconstruction house and brick-concrete building

The framework in the reconstruction of houses mainly used cold-formed steel, which has good seismic performance. The entire framework was connected by bolts, and the villagers were able to build it themselves after a one-time demonstration. The walls were filled according to traditional ways by using local materials. The houses looked identical because of the recycled old materials (Figure 5).

The framework has these other features:

1. Large-scale standardized production. The period of construction was short, which was very suitable for reconstruction;

2. Direct molding of the framework depending on the level of construction skills. This feature was suitable for villagers who built houses by themselves.

3. The openness of the structure. Villagers could easily add a room to the original building because of structural flexibility.

4. Similarity of this architectural framework to the traditional "through type timber frame." Such similarity helped steer the reconstruction of houses toward having the same spatial form as that of traditional houses.

Figure 5: framework of reconstruction house *Figure 6: a double-sided hot-dip galvanized network*

Architect Hsieh Ying-chun was also concerned about a building's energy efficiency and sustainable development. Given that Maoxian is in the hot-summer-and-cold-winter area, the thermal performance of a building during winter should be considered. The main envelope of a house is composed of three layers of exterior walls: the first layer is made of local stone, which has strong local characteristics; the second layer is a double-sided hot-dip galvanized network with concrete-filled gap to effectively reduce the weight of the wall and to increase the strength of the structure to resist horizontal forces (Figure 6); and the third layer mainly uses insulating form board with grass soil, which is likewise used in the main structure of the roof. In this way, the house has good thermal performance. Compared with traditional houses, the roof and three layers of exterior walls can save 45.61% and 39.45% of construction energy consumption, respectively (Du, 2010).

Furthermore, the lesser energy consumption of cold-formed steel compared with clay bricks and the local availability of stones lead to effective control of CO_2 emissions.

5.2 Ma'anqiao Reconstruction Project

Ma'anqiao is a small and poor village located in the impoverished mountainous area of Southwest China, in the southernmost side of Sichuan Province near the Jinsha River and close to Yunnan Province. An earthquake in August 2008 severely damaged most of the village houses. Rebuilding materials (e.g., bricks) are too expensive for the villagers and are also difficult to be transported across the river. The remote location, poor accessibility, and resource limitations hampered the rebuilding efforts of the villagers. Considering that many other remote villages in Southwest China are similarly situated as Ma'anqiao, the challenge for development workers and rebuilders was "how to make use of local materials to create an anti-seismic, comfortable, and cheap [but sustainable] house." The post-earthquake village reconstruction project in Ma'anqiao Village is the first comprehensive village demonstration project in the poor rural areas of Southwest China after the 2008 Wenchuan earthquake. Professor Edward Ng of the Chinese University of Hong Kong and his team from the Wuzhiqiao Foundation worked on the project for three years.

Before the initiation of the design work, the team conducted a series of survey and investigation in the village, communicated with the villagers to define the key problems, and conducted research to find an appropriate solution (Figure 7). This project provided several designs suitable to the needs of different family sizes. Villagers could choose the appropriate design according to their own needs.

The old rammed earth building has poor seismic performance because the building's foundation is not solid enough, and the tensile strength of mud wall is insufficient. After a series of investigations, the team invented and proposed a series of anti-seismic designs and strategies. Timber frame inside the mud wall became an important part of an effective anti-seismic design, and a building's foundation with appropriate size and correct cement mortar enhanced the integrity of houses. Bamboo strips, which are embedded into the mud wall, can bond the frame with the walls; some concrete belts were added into the wall to improve structural integrity and to avoid vertical cracking. Light lime and cement were added into the mud to strengthen the wall. Ramming tools were improved to pound the mud better by fitting them with iron heads (Wan, 2013). The resulting anti-seismic rammed earth building could satisfy the demand of seismic fortification in the area (Figure 8). The cost of per square meter is $32 which is only 20% of brick-concrete building in nearby village.

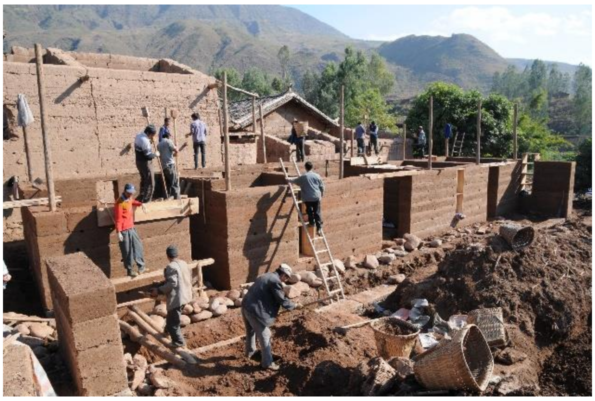

Figure 7: communicate with villagers *Figure 8: build a demostration rammed earth house*

The traditional rammed earth houses in this village were ill ventilated and dark. Therefore, windows of proper sizes and cross ventilation were provided to improve daylight and natural ventilation (Figure 9). Biogas has since then been used to turn waste into fuel for lighting and cooking. Water cellars were built to supply clean water from the nearby spring instead of people directly collecting "dirty" water from the river. In addition, storm water was naturally channeled to the land.

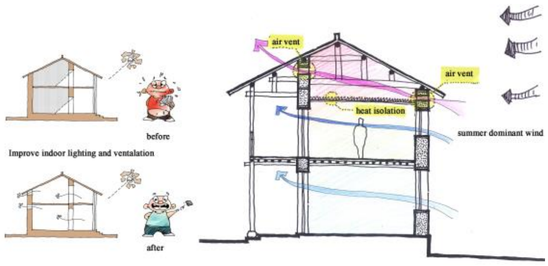

Figure 9: improve indoor lighting and ventilation *Figure 10: the round yard of village center*

After the rural houses have been reconstructed for basic living needs, a village center with a clinic, reading room, kindergarten school, shops, and other facilities was built to provide public space and to make its facilities available to the villagers. The village center could also function as an ethnic cultural exhibition center and was built in a round yard because Dai and Yi people prefer dancing together in a circle to celebrate festivals or for entertainment (Figure 10). This yard has become a public communication space and could maintain the minority culture of the village.

As in the Yangliu Village, the villagers of Ma'anqiao were employed in the reconstruction process. Given the effective, economical, and easy-to-learn anti-seismic strategies, the villagers were able to build their homes by themselves without hiring a contractor and without using complex technology. The occupied houses were also inexpensive and easy to build and repair. In this way, the villagers built anti-seismic rammed earth houses and learned an economical way to make their living. The idea of the project was to transfer knowledge and skills during the construction process rather than merely teaching the villagers using drawings.

5.3 Discussion

The case studies show that both of reconstruction projects fully respected the traditional cultures and the autonomy of villagers and also made rational use of local materials and local technology to rebuild the rural communities. The concept "collaborative construction" not only provided an opportunity for the local labor force to learn new skills but also reduced the economic pressure on house construction. The two cases also considered the reduction of environmental and ecological damage in the entire process. Case 2, in particular, was an overall reconstruction project of a community, and its supporting facilities (i.e., construction of village center, setting up ecological toilets, and promoting public health awareness) have good social effects. The sustainable practices of Village level (ie. the orientation of houses should respect to climate, rain water harvesting system and water supply etc) and settlement level are also important aspects for this study. Due to the space constraints, the related strategies will be discussed in the further study.

6. CONCLUSION

Endogenous development emphasizes the concept of sustainability and focuses on the importance of humans living in rural areas. Endogenous development suggests a self-sufficient, regional characteristics-based model that is suitable to the situation of poor rural communities in Southwest China, which have poor transportation and backward economy. This model can also reduce the communities' dependence on inward investment by emphasizing the use of local resource and traditional core values. The discussed strategies could provide a systemic way to further study sustainable renewal in the poor rural communities of Southwest China.

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Urban Biophilic Theories uponReconstructions process for Basrah City in Iraq

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ABSTR ACT

Basrah is the most beautiful part of Iraq. In terms of size, it is the second largest city after Baghdad. For more than 25 years, Basrah has almost constantly been at war or been in an Aggressive situation. Three major conflicts have dominated, from 1980 to 2003. The wars have brought great suffering to the Basrah population and city. The bombing caused great material damage. Today with reconstruction process the city require to take a stabile process of reconstruction by using environmental cods in urban planning and design which offer an exciting opportunity to achieve environmental, social and economic benefits. The concept of biophilia deserves a deeper explanation. The hypothesis is that this affiliation leads to positive responses in terms of human performance and health even emotional states. The new movement aims to create environmentally friendly, energy-efficient buildings and developments by effectively managing natural resources. This path will discover a far deeper integration of nature with the built environment and the potential synergies in exchanging energy and nutrients across the human-nature interface. The research will take in reading different experiences from 1980 until now, in which we will try to put all practical consideration necessary to be able to select competent urban and architectural elements adequate to Basrah condition.

INTRODUCTION

An urban settlement, town or city, is one of the primordial and predominant expressions of human sociability on a territorial basis. The outward, visually perceptible manifestation of the complex, multiform social structure that constitutes a town is the three-dimensional plastic townscape [Acta Tongressus madviciani 1958]. A sustainable city is organized so as to enable all its citizens to meet their own needs and to enhance their well-being without damaging the natural world or endangering the living conditions of other people, now or in the future [Herbert Girardet 1999]. Arid zones are characterized by various conditions that can be affected by different combinations of physical determinants. Planners must decide which conditions are desirable and adopt criteria designed to maximize them in selecting the best site for a new settlement [Gideon Golany 1977]. The region of Basrah, the city of Sinbad, is, some would say, the most beautiful part of Iraq. It is Iraq's second largest city and principal port. Its commercially advantageous location, localize near oil field. In 1948 many oil refineries have been built in the city. It is an area of countless birds and a variety of animals, full of trees and gardens and canoes

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gliding on the mirror-surfaces of calm lagoons [Amjad Almusaed 2004:14]. The human being entered the third millennium without the hope of achieving permanent peace on our beautiful earth, sustainable development and equality for all. We must seek what we have in common, namely, codes of understanding [Amjad Almusaed 2004:11]. A biophilic city is a healthy city, a city with abundant nature and natural systems that are visible and accessible to urbanities. It is certainly about the physical conditions and urban design parks, green features, urban wildlife, walkable environments, but it is also about the spirit of a place, its emotional commitment and concern about nature and other forms of life, its interest in and curiosity about nature, which can be expressed in the budget priorities of a local government as well as in the lifestyles and life patterns of its citizens. [Timothy Beatley 2011:13]. Natural and biophilic elements require being significant in everything and anything we design and build, from habitations, schools and hospitals to neighborhoods and urban configuration, to street and road structures and larger urban- and regional-scale design and planning. One of the classics of town and country planning is a garden city movement which it founded and inspired, has had a profound influence on town planning throughout the world, though its essential proposals are only now beginning to be properly understood and applied. Garden City history is that it carried further than Letchworth the technique of civic design and architectural harmony, and in the organization of its shopping center and factory area, it conducted interesting experiments which merit careful study by all who are concerned with the economics of large-scale development [Ebenzer Howard 1918:2]. Garden City is a Town designed for healthy living and industry; of a size that makes possible a full measure of social life, but not larger; surrounded by a rural belt; the whole of the land being in public ownership or held in trust for the community [Ebenzer Howard 1918:5].

There are several obstacles prevent us to achieve a biophilic city and/or neighborhood, and many interruptions in contemporary life navigate as far afield from nature. Such technological interruptions as digital communications devices are often seen as substantial permanent factors in our rising interruption with the natural ecosphere. Biophilic cities reflect a humility that understands the wisdom of nature and natural systems and the need to learn from them and model design and planning after them. McDonough is famous for imploring us to design “buildings like trees, cities like forests.” A city the functions like a tree is a model for our time, as we imagine cities that are carbon neutral and energy-balanced (that produce as much power as they need and live within the limits of current solar income), that are zero-waste, and that integrate and celebrate diversity (from which cities will become more resilient in the face of climate change and a highly dynamic world) [Timothy Beatley 2011:49].

CLIMTE CONDITIONS IN ACTING THEATER

The average temperatures in Basrah range from higher than 48 degree ºC in July and August to below freezing in January [Gideon Golany 1977:6]. The summer months are marked by two kinds of wind phenomena: the south and southeast, a dry, dusty wind with occasional gusts to eighty kilometers an hour, occurs from April to early June and again from late September through November. Basra climate is hot, dry summer, cold winter, and a pleasant spring and fall [Daniel E. Williams 2007:32]. Roughly 90% of the annual rainfall occur between November and April, most of it in the winter months from December through March [Amjad Almusaed 2004:12]. The remaining six months, particularly the hottest ones of June, July, and August, at approximately 32 ºC, air dry. The influence of the Arabic Gulf on the climate of Basrah is limited. But near the gulf the relative humidity is higher than in other parts of the country. Most nights are clear in the summer, and about one third of the nights are cloudy in the winter [Amjad Almusaed 2004:13].

PROBLEM PROPOSED

There were two major catastrophic actions caused a great environmental catastrophe over Basrah city from 1980 until now. The first starts after the terrible consequence of the Iraq –Iran war and recently USA attack over Iraq the urban green covering disappeared from large areas of the city, beside the extension of the city development axes over the green areas. The negative effect of the heat island phenomenon over the city area, consequently the human's thermal comfort becomes more perceptive [Amjad Almusaed 2004:176]. Other action was after the decision of the Iraqi regime over the south Iraqi marshes, which is located in the north part of Basrah city. The Mesopotamian Marshlands, nearly destroyed in the 1990s, have been partially restored but remain at risk. The Mesopotamian Marshlands are the largest wetland ecosystem in the Middle East [William J. Mitsch et al 2010]. Construction of numerous dams, water diversions and hydropower facilities on the Tigris and Euphrates Rivers over the past century and the deliberate draining of the marshes by the Iraqi regime in the early 1990s had almost destroyed the wetlands by 2000 [Aoki, C. and Kugaprasatham, S. (2009)]. Iraq's southern marshes were a historic area, which had been a traditional hideaway for rebels. They were the largest wetlands in the Middle East, and some believed they were where the first human civilization began.

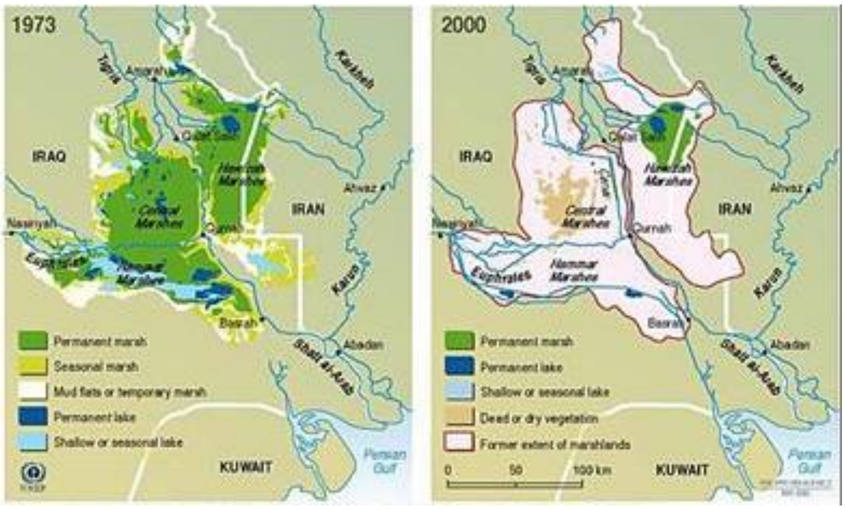

Figure 1 The southern marshes before and after Saddam's campaign of destruction[Herbert Girardet 1999]

Ecosystem recovery, however, has been seriously undermined by a severe drought (2008-2010) and uncoordinated water-related developments in the Tigris-Euphrates basin [Garsteck and Amr 2011]. The lack of a water sharing agreement between riparian countries and potential declines in Euphrates flows are a major threat to the wetlands' survival [Herbert Girardet 1999]. Today we can observe clearly the negative effect of urban heat island in the center of Basrah city, precisely in physical frameworks of the city, where we can detect a typical phenomenon with a large negative effect for the period of summer heating that is a natural thermodynamic phenomenon. International sanctions are supposed Iraq in 1990 prevented the development process of the civil city requirements. Therefore the city requires many civil elements. The major negative acting is:

- Basrah is a rich petroleum city; therefore city development axes are under governor petroleum minister control.
- A bad city zoning after 1989's reforming

The city today is in a bad condition, where the main urgent requirements are:

- A huge requirement for residential units for more than 1.5 million inhabitants
- Efficient social and cultural zones
- Additional open green areas

- Efficient management of vernacular buildings existent
- Competent and suitable civic centers and arteries

Sustainable cities are created by people who are knowledgeable about sustainable solutions. Decisions about sustainable development made by people whose have knowledge of the opportunities and implications inherent in sustainable choices. Decision makers can only choose sustainable solutions if they know they exist. Arid settlement and development in virgin areas require, as we noted, vision and pioneering spirit or ideological motives in the young, dynamic settlers for quite a long time after its initiation [Golany, Gideon S. 1995:4].

DISCUSSIONS AND RECOMMENDATIONS

Good stories and narratives are crucial to change in the future. Key questions are therefore:

- How town's functions do is that we make a difference in the city?
- What visions they have for how they can and will contribute to the city in the future?

We are looking to condense and in outline form / imagery to translate into a strategy proposal [UNITED NATIONS CONFERENCE ON HUMAN SETTLEMENTS (HABITAT II)]. Understanding the natural history of a city helps us to see cities as ever-changing, ever-evolving palettes of life [Timothy Beatley 2011:14]. The study aims to achieve an overall development strategy with the following strategies:

Activation of vernacular concepts of urban texture structure

Where vernacular habitat units are compact with interior courtyard; the streets are sinuous and pass through houses volumes. The shady interior courtyard has the effect that the rooms do not communicate directly with the overheated air outside, but through intermediate buffer spaces. Windows are often protected from the appalling [Amjad Almusaed 2004:23].

Moving towards a compact urban city

A compact form can reduce the length of utility networks, the maintenance they require, and the expenditures of energy and thereby prove economical. However, such a form mandates special designs that may increase construction cost [Golany, Gideon S. 1995:16]. It is necessary to create a more judicious urban microclimate than that dominant in the neighborhoods. They have to reflect the requirement for verticality (as opposed to horizontally) in the conceptual process of urban structures; this could involve some subterranean construction.

Implementation of a Linear City model

In old regions of the city we can implicitly, the concept of the linear city to rebuild and recover the deteriorate regions of the city, in a new ecological one that can go beyond the laws and restrictions of Iraqi petroleum ministers, where the main feature of the linear urban form is its ability to deal with the rapid and efficient mass movement of people and goods within and between cities. A further quality of the linear structure is its ability to deal, in theory, with infinite growth. Fig. 2 shows the possible extension in linear of the city by axes and the positioning of civic centers.

Figure 2   the possibility of linear city extensions by axes and civic centers

In this context, it be required to respect the following parametric factors:

- Divide Basrah in a great main center includes all private and public buildings, and many other small centers. The centers can be connected through a large classified transport network.
- A better organization of the Basrah has to divided city in many different levels
- The city has to be built by determining an urban point called 0 zone. Development process and city orientation start on this form.
- The city's borders have to be Determined through roads and streets.
- City district and development process can be arises by redefinition of the streets and buildings with sustainable vision
- Divide the city in many environmental zones can help in improving the macro- climate
- The city has to give city coherence through a clear road and transport networks.
- Conversion of Basrah marsh has to be built in an optimal way.

Application of bioclimatic architecture policy

The building design likewise should be governed by the climatic realities. The architecture itself is important, as are the shading devices, the landscaping, the shielding that a designer provides against adverse conditions, and the ventilation. The heating and air-conditioning plants of a structure must be designed with the climate in mind. Another very important element in arid-zone building design is insulation, because it is the one thing that tempers extreme outside variations in climatic factors. The easiest way to reduce the variations between daytime and nighttime temperatures is to put something between the inside and outside worlds: insulation does just this [Golany, Gideon S. 1995:32].

Initiated the concept of biophilic city and healthy environmental concept

The biophilic structure of the earth is a valued and appreciated part of life, where areas and human carrier green is not only an excellent synthesis of both qualitative and quantitative research that documents the bond between people and plants, it is a synthesis of the life's work and thinking of one of the most important figures in people-plant relationships. A biophilic community is a place where residents can easily get outside, where walking, strolling, and meandering is permissible, indeed encouraged, and evidence suggests that these qualities now carry an economic premium [Timothy Beatley 2011:3]. A green building uses considerably less energy and water than a conventional building, has fewer site impacts and generally higher levels of indoor air quality [New York City Department of Parks and Recreation]. It also accounts for some measure of the life-cycle impact of building materials, furniture and furnishings. These benefits result from better site development practices; design and construction choices; and the cumulative effects of operation, maintenance, removal, and possible reuse of building materials and systems [Jerry Yudelson, 2006:19]. A biophilic city is one that is full of varied sights, sounds, smells, and textures, many, but not all of which are natural [Brian Burton 2009].

First of all, an urban area invariably absorbs more heat from the sun than does an undeveloped one because the building materials usually have an albedo lower than that of most natural land environment. Thus, they necessarily absorb more energy [Ken Yeang, 2006:294]. Second, an urban area rejects man-made heat because machinery, combustion processes, and a man in a city are heat rejecting [Gideon Golany 1977:33]. The urban heat island mitigation strategies, can support to diminish direct energy utilize in buildings, and if applied in a community-wide basis, can decrease generally ambient air temperature in a specified region [Gallo, K.P.; Tarpley, J.D (1996)]. There are many assumptions, average leaf, and average plant. Hospitals and health facilities utilize the therapeutic benefits of green areas [Wolf K. L. 2007]. . These facilities sometimes use gardening as a tool to enhance the healing process for patients. In addition, the person can enjoy the comfort, fresh air, and landscape while restoring their health [Ismail Said (Jun 2003)].

Reducing of CO2 emissions and increasing energy saving and efficiency concept

We require to control the traffic-systems reduction, distraction and rerouting to reduce the production of air and noise pollution, and heat discharges. For parking the optimal solution is in building vehicular parking spaces underground or as covered structured parking. Use an open-grid pavement system (with impervious surfacing such as porous concrete) for the parking-lot areas [Ken Yeang, 2006:318]. Reducing carbon dioxide emissions from the building sector is critical to our ability to combat global warming. Green buildings are an important component in the effort to bring carbon dioxide emissions back to 1990 levels, as required by the Kyoto Protocol, so that we can begin to stabilize carbon dioxide concentrations in the atmosphere at levels no more than 20 percent above todays [Jerry Yudelson, 2006:41]. Topography by vertical variations in the landscape is helpful in creating potential energy saving idea. Gravity is one of the most significant sustainable forces. It can distribute water for free, and even stratification of microclimatic air temperature is related to its presence.

Increasing of environmental, human thermal comfort

Communities can take as many steps to lower the temperature of the environment. These temperature reduction strategies include: By means of the greater concept of biophilic city, vegetated green roofs, living green walls and planting trees and vegetation employ the evapotranspiration and evaporative-cooling procedures of vegetation on construction surfaces and integrate open green spaces. In addition, trees, shrubs, and other plants help reduce ambient air temperatures during a process known as "evapotranspiration." This happens when water absorbed by vegetation evaporates off of the leaves and surrounding soil to naturally cool the surrounding air. Trees also insert oxygen to the atmosphere, break down a quantity of pollutants and diminish dust [Amjad Almusaed 2004:231].

Decreasing the level of heat-absorbing surfaces

Adjust current and new urban city block layouts and configurations with explain patterns, materials and surfaces that absorb a small amount of solar energy [Berdahl, P. Bretz, S., 1997:25, 149-158]. Building materials and finishes appropriate to the impacts from the climate and the weather. Earth building can achieve great heights of structural and aesthetic achievement [J.C. Moughtin 1985:21]. Earth can be used in a variety of ways which encompasses a wide range of architectural styles and aesthetic appeal [Peter Shirley, J. C. Moughtin 2006: 30].

Facade cladding systems is a most popular building material uses for façade in Basrah today. It's made of different materials such as steel, aluminum, Cor-Ten and glass. The material absorbs a huge amount of heat in the day at summer period and its release it at night. It works such as thermal mass. The montage of this material in Basra is without thermal insulation. This contributes in amelioration of the heat island phenomenon. Application of other environmental material is essential today. [Myer, W. B (1991)]. The current surfaces (roofs, infrastructure, pavements, etc.) with vegetated surfaces such as green roofs or green gardens and open - network road surface or specify cool materials to decrease the heat absorption. In other hand, we need to employ the well reflective and high emissivity building surfaces, materials upon walls and roofs, or by installing of a green roof or walls. Therefore, we have to increase the reflectivity of building surfaces such as rooftops and using frequently of light colors to create a highly reflective building climatic surface to keep buildings cooler in summer season to reduce energy consumption

CONCLUSION

Planning and architecture must work together to be sustainable. To design sustainable is to integrate the design into the ecology of the place the flows of materials and energy residing in the community [William D. Solecki, et al,2005]. One of the major problems facing us is how to establish and maintain environments that support human health and at the same time are ecologically sustainable. Green areas seem too important to people. Most people today believe that the green world is beautiful. Biophilic habitats are still often seen as an unadulterated esthetical element in architecture, as a spleen of some “Greenies”. In fact, green areas by now contribute, some extent, to a better microclimate through evaporation, filtering of dust from the air and reduce inside temperatures at the building's surface. Besides improving the microclimate and the indoor climate, the retention of rainwater is another important advantage. The aesthetic form requires, escalating the value of the possessions and the marketability of the building as a complete, mainly for accessible green areas. Urban and regional planners should view the world's arid zones as potential locations for future urban expansion and for food production, and as energy resources. No matter what function these areas serve, the construction of settlements of different forms and functions which respond to the unique nature of a desert climate will be needed. Generating more biophilic cities will also necessitate political governance, of course, and there are currently strong suggestions that politicians are capable to gain political benefits from sustenance for green developments. The green areas can take a differ places in relation to the non-greenly areas where the green area appearance aim to be synchronized by means of another area in concordance with architectural perception upon biophilic habitat.

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Design Science to Improve Air Quality in High-Density Cities

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ABSTRACT

In high-density mega cities, air pollution has a higher impact on public health than cities of lower population density. Apart from higher pollution emissions due to human actives in densely populated street canyons, stagnated airflow due to closely packed tall buildings means lower dispersion potential. The coupled result leads to frequent reports of high air pollution indexes at street-side stations in Hong Kong. Therefore, high-density urban morphology design science is needed to lessen the ill effects of high density urban living. This study addresses the knowledge-gap between planning and design principles and air pollution dispersion potential in high density cities. The air ventilation assessment for projects in high-density Hong Kong is advanced to include air pollutant dispersion issues. The methods in this study are CFD simulation and parametric study. The SST κ- ω turbulence model is adopted after balancing the accuracy and computational cost in the validation study. Urban-scale parametric studies are conducted to clarify the effects of urban permeability and building geometries on air pollution dispersion. Given the finite land resources in high-density cities and the numerous planning and design restrictions for development projects, the effectiveness of mitigation strategies is evaluated to optimize the benefits. A real urban case study is finally conducted to demonstrate that the suggested design principles from the parametric study are feasible in the practical design of high-density urban areas.

INTRODUCTION

Emissions from motor vehicles contribute to air pollution in urban areas, particularly at street canyon level. The European Environment Agency (EEA) (2012) has reported seven types of pollutants that urban dwellers are exposed to. All of these pollutants are primarily or secondarily related to road traffic emission (fossil fuel combustion). The World Health Organization (WHO) (2008) has therefore explicitly recommended the concentration limits for various air pollutants such as O_3 and NO_2. The risks associated with exposure to air pollution are relatively low for individuals but are a significant public health concern (Kunzli et al., 2000). Understanding the problem in densely populated urban areas from the urban and city scales is therefore paramount.

To decrease traffic pollution, an improved vehicle emission control program has been implemented in Hong Kong by the Hong Kong SAR Government. Nonetheless, the roadside concentration of NO_2 continues to increase (Environmental Protection Department, 2011). Similar findings are also being reported in Europe by EEA (European Environment Agency, 2012). High hourly, daily, and annual average concentrations of NO_2 have been recorded at the road-side stations in the Central, Causeway Bay, and Mong Kok in Hong Kong. Air pollution far exceeds the limits recommended by the WHO (Environmental Protection Department, 2011). These three areas are high-density metropolitan areas and traffic hotspots. As shown in Figure 1, vehicles crowd the streets of these high-density urban areas. The reported higher concentration of NO_2 is the result of the larger NO_2 percentage in total traffic emissions (European Environment Agency, 2012; Grice et al., 2009) and of poorer urban air ventilation in high-density urban areas (Ng et al., 2011). The bulky building blocks, compacted urban volumes and very limited open spaces seriously block the pollutant dispersion in these deep street canyons (Tominaga & Stathopoulos, 2012). Therefore, apart from having control measures to decrease vehicle emissions, understanding pollutant dispersion as related to the urban planning and design mechanism is necessary in order to guide policymakers, planners, and architects in making better evidence-based decisions.

Figure 1 Vehicle fleets in the deep street canyons of Mong Kok and Wan Chai in Hong Kong; high concentration of NO_2 is frequently measured at the roadside stations in the areas.

The Severe Acute Respiratory Syndrome (SARS) episode in 2003 triggered the Air Ventilation Assessment (AVA) study in Hong Kong. Since 2006, AVA has been implemented as a prerequisite for urban development and old-district redevelopment (Ng, 2009). The 'Sustainable Building Design (SBD) Guidelines (APP-152)' have also been drawn up by the Hong Kong Government. These guidelines allow architects to evaluate the effects of their proposed building designs on the surrounding wind environments, and then to enhance urban environmental design (Hong Kong Building Department, 2006). This study builds on the previous work (Yuan & Ng, 2012) by conducting parametric studies to statistically evaluate and further develop the efficacy of the AVA TC-1/06 guidelines and the SBD's APP-152 guidelines with regard to air pollutant dispersion. This study aims to provide significant and sufficiently accurate insights on the air pollutant issue at the beginning stage of the design practice. These insights are helpful to avoid the mistakes that cannot be easily corrected at the late stages of the design process. The result of this study, as a piece of design science, is intended to facilitate a paradigm shift from the typical experience-based ways of designing and planning to a more scientific, evidence-based process of decision making.

METHOD AND VALIDATION

This study used the Eulerian method to model the air pollutant dispersion. Compared with the Lagrangian method, which considers the species as a discrete phase, the Eulerian method considers phases as continuum and is solved based on a control volume, which is similar in form to that for the fluid phase (Wang, Lin, & Chen, 2012; Zhang & Chen 2006). Wang, Lin and Chen (2012) compared the performance of Reynolds-averaged Navier-Stokes (RANS) model with Eulerian method and Large Eddy Simulation (LES) model with Lagrangian methods. The later one is more accurate but also with higher computational cost. Zhang and Chen (2006) used a user-defined founction in Fluent to calculate the pollutant concentration, because the lagrangian method does not direclty output the concentration value. Therefore, the Eulerian method is more convenient for calculating the air pollutant concentration, which was the index that this study used to evaluate air pollutant dispersion.

In this study, the wind tunnel data provided by Niigata Institute of Technology (Tominaga & Stathopoulos, 2011) was used to validate the Eulerian method. The effects of the different turbulence models on air pollutant dispersion simulation were also investigated in this validation study. RANS and

LES models were included in the validation study. In RANS models, the standard and realizable κ-ε model, Reynolds stress model (RSM), shear-stress transport (SST) κ- ω model were used, in which approaches of dealing with Reynolds stresses are different (Murakami 2006).

Ethylene (C_4H_4) was used as tracer gas, and the tracer concentration was set at 1000 ppm, duplicating the setting in the wind tunnel experiment (Tominaga & Stathopoulos, 2011). The tracer gas was released from the point source in the model with a wind velocity W_s ($W_s/U_b = 0.12$, U_b is the input wind velocity at the building height, 3.8 m/s).

The model configurations were set to match those in the wind tunnel experiment too (Tominaga & Stathopoulos, 2011). The H/W and H/L aspect ratios were set to 1.0 and 0.5, respectively, where H is the building height, W is the width of the street, and L is the length of the canopy. All modeling settings followed the Architectural Institute of Japan (AIJ) guidelines. The input wind direction was perpendicular to the street canyon. Input wind velocity (U_x) and turbulence kinetic energy (TKE) profiles were set by a user-defined function.

The simulation results of the different turbulence models were collected at two test lines and cross-compared in Figure 2. The simulation results were closer to the experiment data particularly near ground (X/H=0.1, X is the height of the test line). However, comapred with LES model with best accuracy, all RANS models overestimated the concentrations at upper lines (X/H=0.5, for example), particularly at the windward side of the street canyon. Among the RANS models, the SST κ- ω model best performed in terms of air pollutant modeling at the windward side. The special near-wall region (the shear layer) treatment by the standard κ- ω model (Menter, Kuntz, & Langtry, 2003) was considered helpful for estimating the air pollutant concentration near surface regions. Balancing the computational cost and accuracy, for this study, the SST κ- ω model was selected as the preferred turbulence model to simulate the air pollutant dispersion in the parametric study.

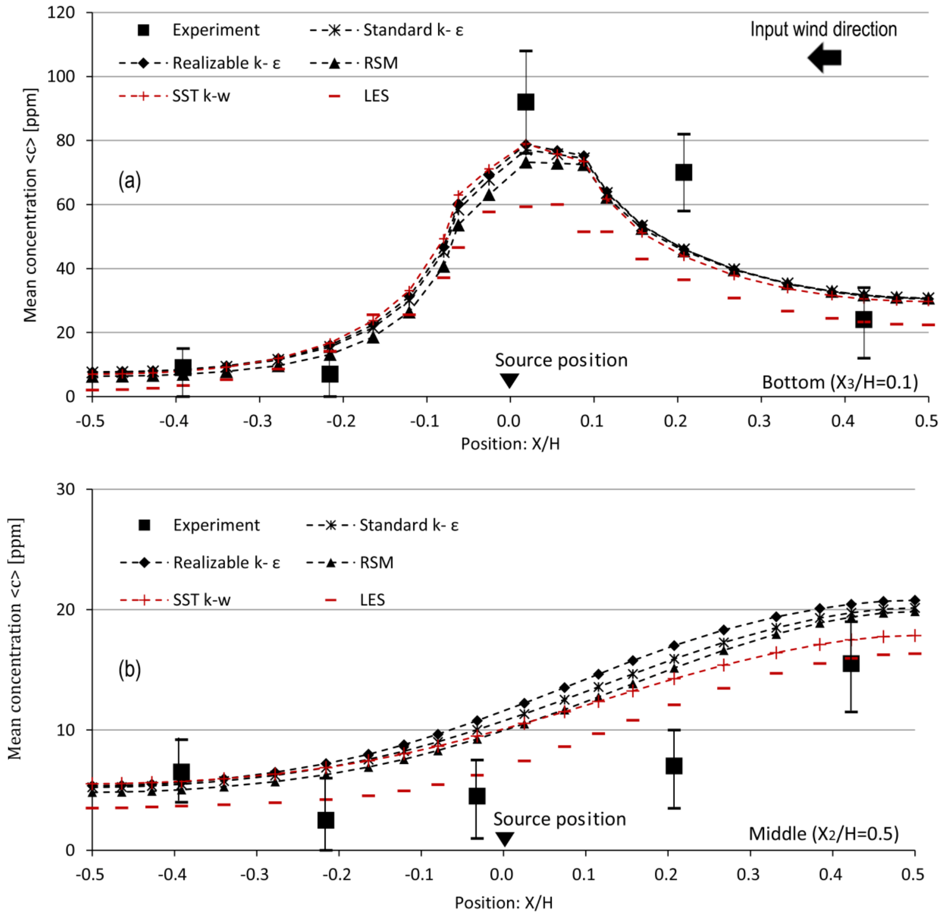

Figure 2 Cross-comparisons of time-averaged concentrations <c> at the street canyon between the wind tunnel experiment and different turbulent models: a) <c> at the bottom line; b) <c> at the middle line. Error bars: standard deviations of the measurements in the wind tunnel experiments.

PARAMETRIC STUDY

The parametric model was at the urban scale and established from urban conditions in Mong Kok (Figure 3), a high-density downtown area in Hong Kong, using a regular street grid. As shown in Figure 3, eight strategy cases were designed to create their corresponding parametric models, establishing a total of eight simulation scenarios with different building geometries and urban permeabilities. Their details were tabulated in Table 1. Plot ratios of Case 3 to 8 were set to be same to that of Case 2.

Given the different building geometries, the corresponding urban permeability of the eight cases were different, as shown in Table 1. The permeability of buildings (P) (Hong Kong Building Department, 2006) and site area ratio (λ_p), which respectively represent the vertical and horizontal permeability, were calculated. High values of P and λ_p indicate low permeability.

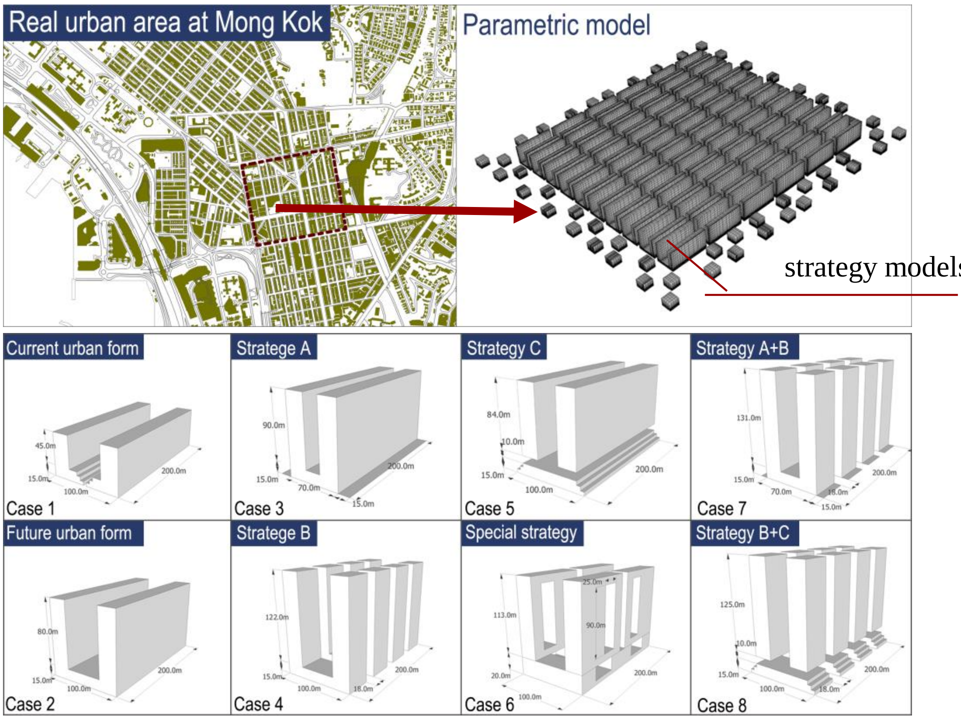

Figure 3 Actual urban area located at Mong Kok, the corresponding parametric model and eight strategy cases.

Table 1 Eight simulation scenarios with different building geometries and permeabilities.

Cases	Building geometry		Land use	Urban permeability			Performance
	Parameters	H (m)	Plot ratio	P	λ_p	λ_i	Percentage of 'pollutant concentration ratio >1'
1	Current urban form	60	8.9	0.9	0.7	0.9	100%
2	Future urban form	95	14	0.9	0.8	0.9	75%
3	Building setback	105	14	0.9	0.5	0.7	70% (Unsuitable)
4	Building separation	137	14	0.7	0.6	0.5	29% (Good)
5	Stepped podium void	109	14	0.8	0.6	0.7	75% (Unsuitable)
6	Building porosity	133	14	0.7	0.8	0.7	33% (Good)
7	Building separation & Build setback	146	14	0.7	0.4	0.3	0% (Excellent)
8	Building separation & Stepped building void	150	14	0.6	0.4	0.4	0% (Excellent)

Note: H: building height; P: permeability of buildings (P = sum of projected building areas/Area of the assessment zone); λ_p: site coverage ratio; λ_i: integrated permeability

RESULT ANALYSIS AND DISCUSSION

This study used the normalized concentration ($\overline{c}$) as the index to analyze the effects of different urban permeability and building geometries on air pollutant dispersion in the street canyon. This was given by:

$$\bar{c} = < c > / < c_0 > \qquad (1)$$

Where $<c>$ is the modeling result of the time-averaged concentration of NO_2 and $<c_0>$ is the reference emission concentration, the norm of $<c>$. Given the definition of $\bar{c}$, the threshold value of $\bar{c}$ was set to 1.0. When the value of $\bar{c}$ is less than 1.0, air pollutants disperse away and do not concentrate in the street canyon.

Building scale analysis

The simulation results, contours of $\bar{c}$ at the vertical sections (Figure 4), firstly indicated that mitigation strategies for the air pollutant dispersion are necessary in the high-density urban planning and design. In current urban conditions (Case 1), air pollutants are seriously concentrated in the deep street canyon. Most values of pedestrian-level normalized concentration ($\bar{c}$) in the street with emission sources were larger than 1.0, indicating that air pollutant does not disperse but concentrate in the street canyon. If current planning and design activities do not change, the air quality will worsen with future urban development (Case 2). Given the negative effects of air pollution on public health and that of the high population density in Hong Kong, mitigation strategies are necessary to alleviate this negative impact.

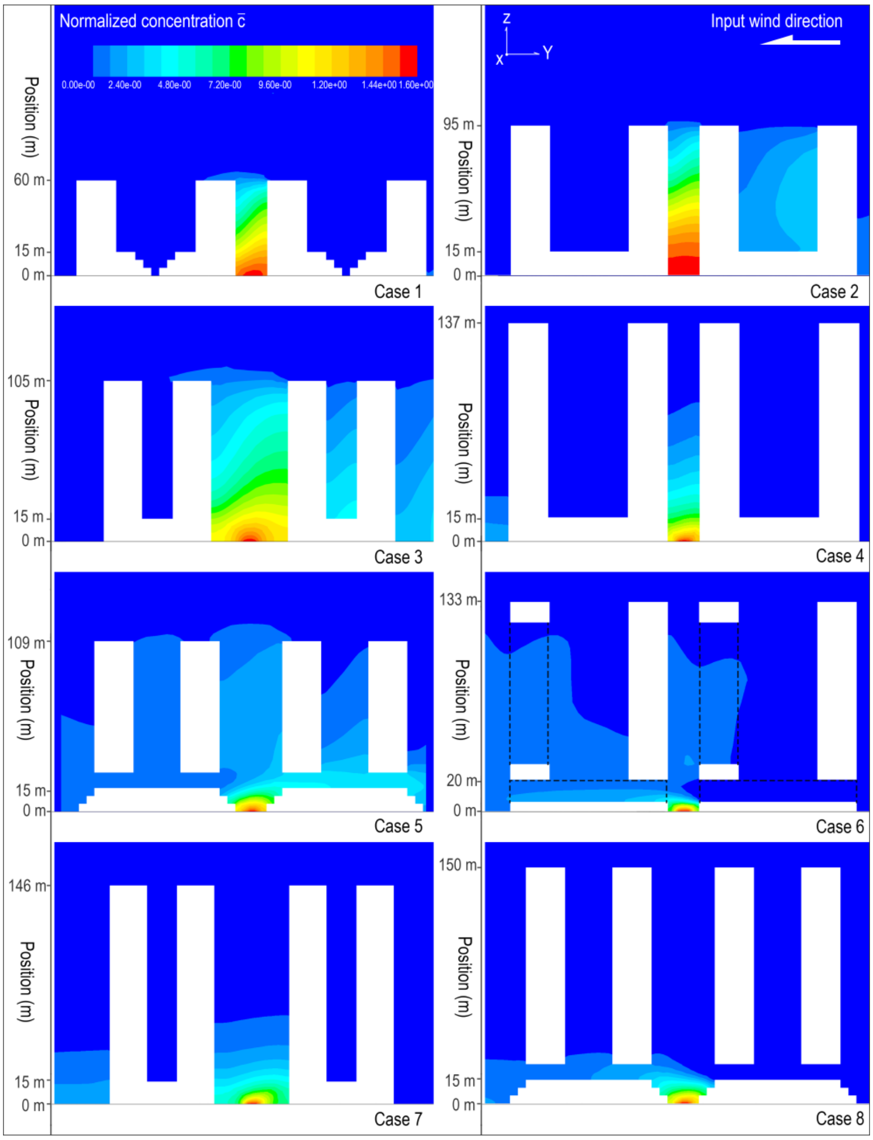

Figure 4 Contour of $\bar{c}$ at the vertical sections in Cases 1-8.

Secondly, the modeling results indicated that the air pollutant dispersion in high-density cities can occur if strategies which promote convection effects, such as building separation (Case 4), stepped podium void (Case 5), and porosity (Case 6), are implemented and could be more efficient than strategies for larger turbulence diffusion, such as building setback (Case 3). Unlike what the AVA knowledge indicates, pedestrian-level pollutant concentration depends on the permeability of the entire street canyon. Although a high building porosity off ground level cannot increase the wind speed at pedestrian level, it can decrease pedestrian-level air pollutant concentrations as Case 6 did in the parametric study. In the design and planning process, appropriate strategies need to be chosen based on the particular concerns in different projects. The performances of various mitigation strategies were quantitatively investigated and tabulated in Table 1, as the practical design reference. Consequently policy maker can determine what and how much needs to be modified in the practical design. Strategies recommended in this study can be applied into both the new project design and the urban redevelopment.

Urban scale analysis

Furthermore, this study conducted a linear regression analysis to statistically weight the effect of permeability of buildings (P) and λ_p (Table 1) on the spatially averaged pollutant concentration at the street with emission. Based on the results plotted in Figure 5, it is clear that the spatially-averaged normalized concentration depends on the permeability of buildings (P) more than on the site coverage ratio (λ_p), as the R^2 for P, 0.78, is larger than the R^2 for λ_p, 0.47.

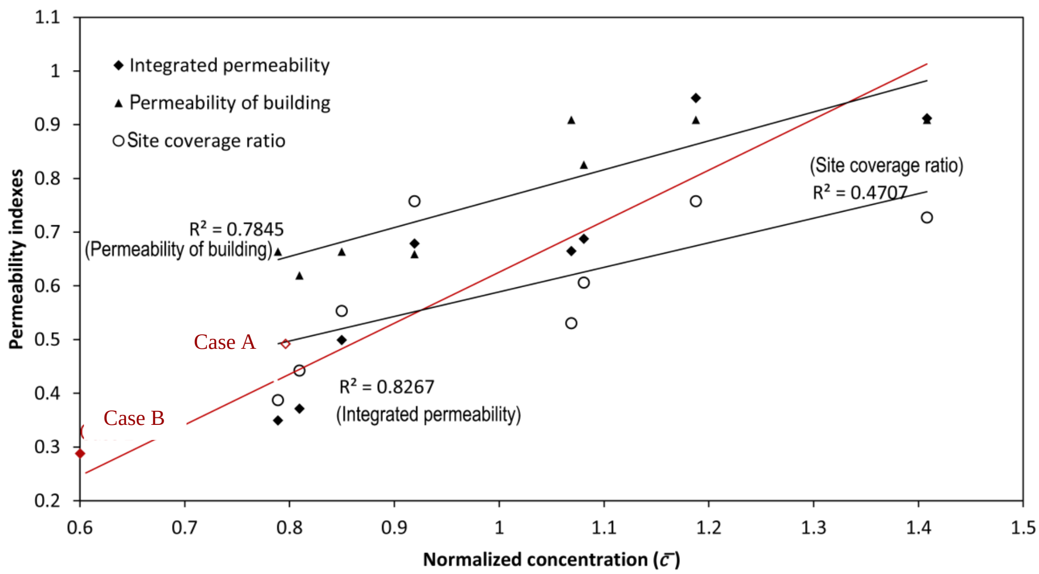

Figure 5 Linear relationships between pedestrian level air pollutant concentration and permeability indexes, P, λ_p, λ_i (Table 1). The values of two real urban Cases, Case A and B, were also plotted. (significant level: 95%)

To better predict spatially-averaged $\bar{c}$ in high-density urban areas, the integrated permeability (λ_i) was calculated based on Counihan's roughness model (Grimmond & Oke, 1999) for estimating urban permeability as following:

$$\lambda_i = (C_1 \cdot \lambda_P - C_2) \cdot P \quad (2)$$

The coefficients C_1 (1.4352) and C_2 (0.0463) were for the contribution of λ_P, considering that λ_P, as the horizontal permeability, is less important than P, as the vertical permeability. The values of λ_i in all eight cases were given in Table 1. As shown in Figure 5, a strong relationship between λ_i and spatially-averaged $\bar{c}$ (R^2=0.83) indicated that λ_i is a better urban permeability index than P and λ_p to estimate traffic air pollutant dispersion. This analysis result makes possible to map traffic air pollutant concentrations in urban areas by using urban morphological indexes in GIS.

URBAN IMPLEMENTATION BASED ON THE REAL CASE STUDY

A real case study at Mong Kok was conducted to demonstrate that suggested design principles and knowledge are feasible in real urban design practice. As shown in Figure 6, based on the current urban morphology (Case A), an urban design was produced (Case B) to improve the local air quality. Based on the characteristic of existing buildings, different mitigation design strategies in Table 1 were employed in street blocks. To avoid reducing the land use efficiency, the plot ratio in these two cases were same, 8.3. The site coverage ratio in Case A and B were 0.51 and 0.42, respectively. The averaged building permeability (P) of the total area was estimated at 0-60m above the ground and was 0.7 in Case A and 0.5 in Case B, as shown in Figure 6.

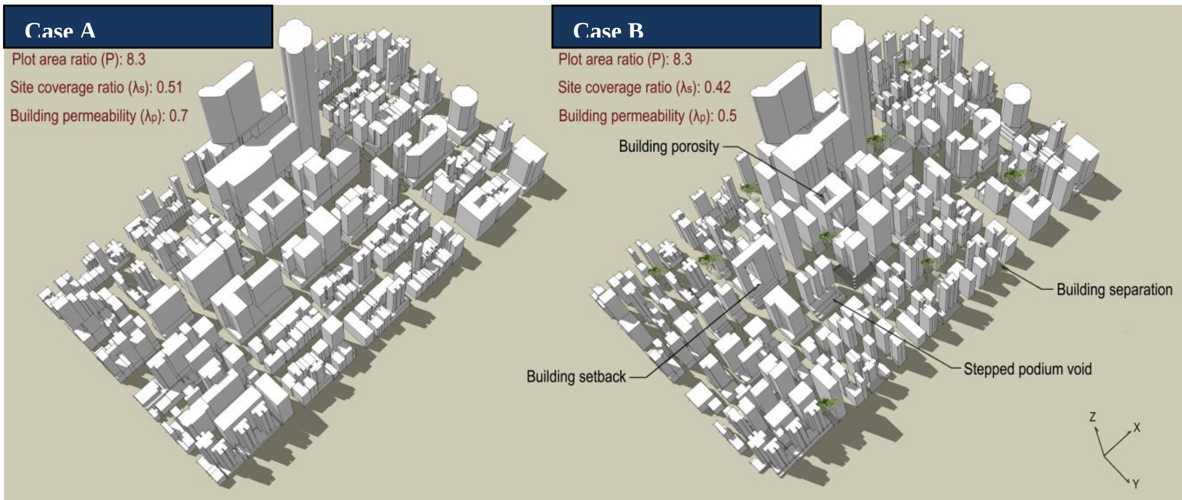

Figure 6 Case study of urban redevelopment at Mong Kok. Case A: the current urban area of Mong Kok; Case B: the urban morphology of Mong Kok with mitigation strategies.

For comparison purpose, a CFD simulation study was conducted to model air flows and traffic air pollutant dispersion in the above two cases. The simulations were constructed in accordance with the methodology in the parametric study. The comparing results in Figure 7 demonstrated that the wind permeability in the entire area significantly increased in Case B. Therefore, Case B significantly increased the local dispersion. The normalized concentration data was collected at the street with emission and cross-compared in Figure 8. It is clear that the probability of high concentration ($\overline{c}$ >1.0) in Case B was far less than the one in Case A. This result validated the suggested mitigation measures suggested by this study.

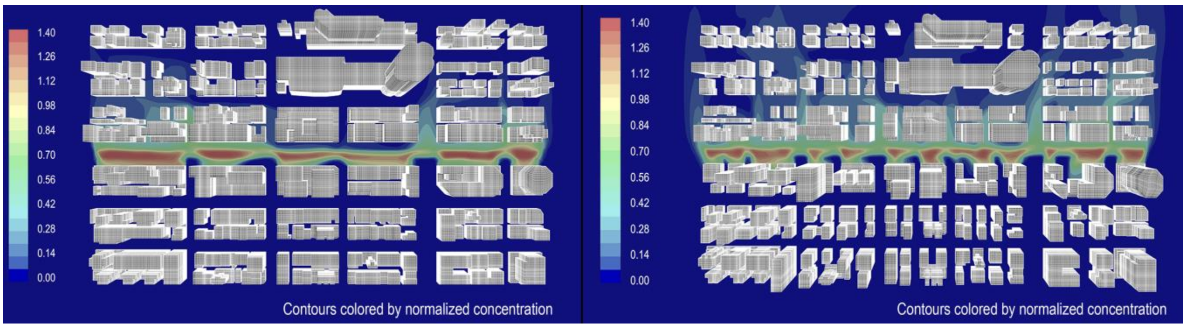

Figure 7 Simulation results. The mitigation strategies in Case B can significantly increase the wind permeability and decrease the traffic air pollutant concentration.

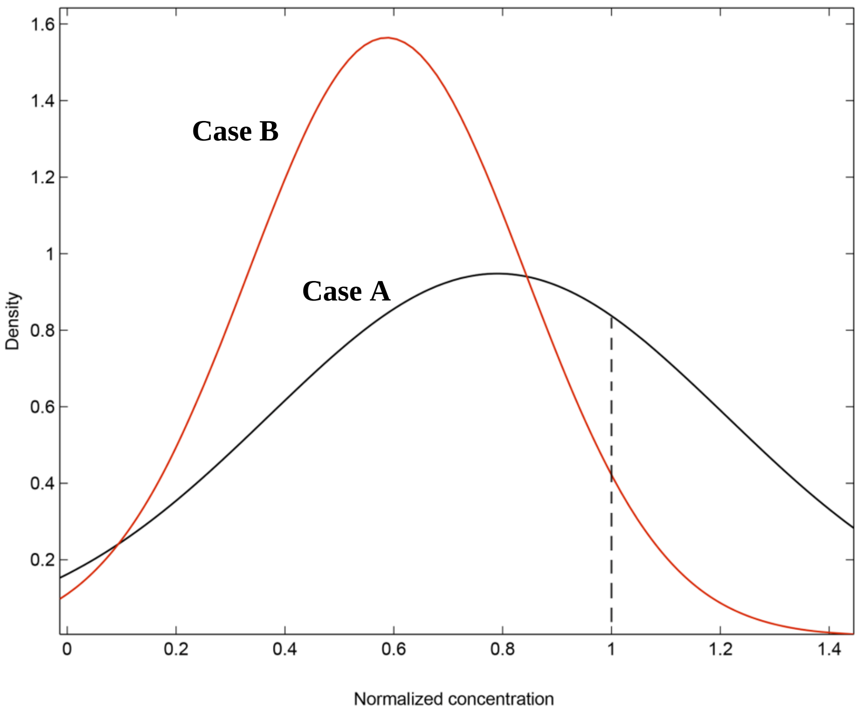

Figure 8 Normal distribution fit of the normalized concentrations in Cases A and B. The probability of high concentration ($\bar{c}$ >1.0) in Case B is far less than the one in Case A.

Based on the Equation 2, the urban permeability λ_i at two real cases was also calculated, which was 0.48 in Case A and 0.27 in Case B. Correspondingly, the spatially averaged normalized concentration ($\bar{c}$) at the street with the emission source decreased from 0.79 in Case A to 0.59 in Case B. These results were plotted in Figure 5. It is clear that these results coincided well with the linear relationship and validated that the supposed knowledge of urban permeability for air pollutant dispersion is feasible in the practical urban design.

CONCLUSION AND THE WAY FORWARD

The planning guidelines for air quality in Hong Kong Planning Standards and Guidelines (HKPSG) point out that '*In the preparation of land use plans, due consideration should be given to the location of major polluting uses with a view to improving the regional air quality.'* and *'Concentrations of NO_2 and particulates are high, particularly at the older urban areas where motor vehicle usage is intense and vehicle exhausts are trapped between narrow roads and tall buildings*' (Chapter 9, Hong Kong Planning Department, 2011). It is clear that the 'due consideration' is needed especially at the existing urban areas. But, meanwhile, the major factors in these guidelines are too rough to make 'due consideration', using only the topography factor. No urban development factors are included. This study clarified the effect of urban development factors on outdoor air quality and provides the practical design knowledge. The architect can choose the corresponding design strategy based on the particular design concerns. The outcomes mainly focused on the building design strategies but urban scale analysis was also included, so that the research has the great potential to be extended for the urban planning implementation.

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Green Space Factor In Modifying The Microclimates In A Neighbourhood: Theory And Guidelines

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ABSTRACT

Cities and rural environments differ substantially in their land surface temperature, which leads to urban heat island effect (UHI). Cities have a dynamic relationship with the microclimate. Landscaping is one of the most effective passive design strategy compared to other passive design strategies in mitigating the UHI effect. The degree of 'greenery' or 'greenness' (Green space factor) is usually defined and measured as the percentage of total urban area that is devoted to open green spaces. The higher the percentage of green cover, the greener that particular city becomes. National forest policy, India states that a 20% to 33% of green cover is considered to be fairly good. The green spaces help to alter the temperature, reduce the urban heat island effect and improve the air quality. In most cities, concentrated vegetation is seen only in parks or recreational spaces. This lowers temperatures on the microclimate of the park but does not have any effect on the microclimate of the neighbouring built environments. By placing vegetation within the built space of the urban fabric, the effect of UHI effect can be reduced where people live, work and spend most of their lives. Such approaches have been investigated in the fields of planning, urban design, landscape architecture, environmental engineering. Selection of right plant in the right place can be based on many aspects such as its thermal performance. It further depends on various plant typologies and their characteristics which will have significant role in urban heat balances by reducing the land surface temperature and reduce energy consumptions in the dense built up areas. It also helps to improve the microclimate performance in the built environment and also create a visually appealing environment compared to other passive techniques. This paper describes the importance of relationship between green space factor and microclimate and implementation of these guidelines in a neighbourhood with various case examples from research papers, literature and theories. The study has been carried out with on site observation and Envimet simulation methods.
Keywords: urban heat island, green space factor, green spaces, Envimet

1. INTRODUCTION

Climate, buildings, and green spaces have been explored worldwide by many researchers due to their interesting interrelationships and significant impacts to the environment. In recent years, urban heat island effects(UHI), induced by urban form, anthropogenic heat from buildings and Air conditioning systems have been studied extensively in cities around the world (1). Since the mid twentieth century, the global surface temperature has increased by 0.7±0.18°C during the 100 years ended in 2005. Thus the increased temperature is connected with increase in UHI through expansion of built up areas and populated area. The heat island during daytime increases rapidly and takes 3-5 hours to reach the maximum after sunset. These increased temperatures have implications on electricity, energy consumption and use of resources which inturn affect the environment. The most sustainable solution to these energy and environment problems is following more natural passive cooling techniques. Urban green spaces can directly or indirectly affect local and regional air quality by modifying the urban climates. Many studies have highlighted how landscape in urban design and planning can improve microclimate and thermal comfort (2). Plant processes such as photosynthesis, Evapotranspiration helps to reduce the Mean radiant temperature and anthropogenic heat generated from the buildings which leads to urban heat island effect. This in turn reduces the cooling load of the buildings. The environmental conditions of urban green space have significant impact on the comfort conditions experienced inside them especially in seasons of stressful climate and the development of sustainability in cities(6). Many researchers agreed that plants have an effect on the urban temperature and the cooling loads of building (6, 8). For instance the air temperature distribution was closely related to the distribution of greenery in the urban areas where for some large urban park, the ambient temperature was 2-3°C lower than surrounding built-up areas and it shapes a pleasant urban environment (14). Furthermore, the effects of plants density, plants species, plants distribution and large space of greenery give a large impact, where greenery reduce the surface temperature and urban heat effect (11). Green interventions in terms of trees, shrubs, ground covers, green roofs, bioswales or rain gardens, green walls, permeable pavement may be adopted to achieve comfort and reduce UHI in urban areas. These green interventions are to be quantified to achieve the specific green space factors. The main objective of this study is to find the effect of the green space factors in modifying the microclimate.

2. GREEN SPACE FACTOR CONCEPT

In the literature reviewed, the primary metric used to mesure the percentage of green spaces under the land cover based on the plant types such as lawns, turfs, shrubs and trees are their biological parameters such as LAI – Leaf area intensity, LAD – Leaf area density. There are several benefits associated by incorporating plants in the neighbourhood. There are remarkable efforts being made at different scales for the different types of green space factors which are developed across the world. Table 1 shows the examples of such initiatives across the world; California's attempt to reduce C02 emissions by 25% by 2020 (5); Vancouver's Eco- Density initiative (7); Portland's effort to reduce stormwater runoff (1); from an urban landscaping viewpoint, Biotope Area Factor (3), Seattle's Green Factor (10) Green Plot Ratio (15), and Malmo Green Space Factor (9), which discusses the usefulness of various Green Factor. These green rating systems are designed to examine the relationship between the Green factors or the landscape elements and their performance in the built environment. The green factor systems are designed to increase the quantity and quality of planted areas while allowing the flexibility for developers and designers to meet development standards. These studies deal the metric of green spaces at the scales from one dimension to three dimensions but there is no evidence whether these metrics are climatically sound. This study analyses the performance of these green space factors.

3 METHODOLOGY

Methods to study the green space factor in modifying the microclimate include both numerical modeling and empirical analysis, such as using on site measurements using instruments and weather data obtained from nearest weather stations. With empirical data, the study can be more specific, but have limitations on time and space. Thus, to have a theoretical understanding of performance of different vegetation scenarios and their effects on the microclimate, numerical modeling with on site observations is required. The simulation has been carried out with the help of Envi-met models and simulated alongwith initial onsite observation which was conducted on 20.03.2014 for the climate monitoring and the plant distribution was accounted. In this paper, different scenario such as (i) with existing base case, (ii) nil vegetation, (iii) with turfs and (iv) with trees was selected to assess the air temperature. For the selected sites, the green plot ratio (15) has been applied and evaluated for its performance on the microclimate.

Table 1. Green metrics and policies used around the world(15)

Category of metric	Place	Green metric	Goals	Description and characteristics	Year
One dimensional		Inventory of plants	To increase the number of plants	The number of plants being managed in an area. Simple to use for homogenous or hetrogenous plant populations. Does not provide information on plant species	
Two dimensional	Berlin	Biotope Area factor	Retain high densities of development, whilst also developing the city's green infrastructure	Attempts to account for various types of ecologically effective or environmentally friendly green systems	1994
	Malmo	Greenspace Factor	Increase of green space per inhabitant from $33m^2$ to $48m^2$ in the urban area and increase the area of accessible green space in the countryside from 2% to 33%	Quantifies the planting area. Does not account for vertical stacking.	2001
	Portland	Portland's Green Building Policy	All new City-owned facilities to include an eco-roof systems	Advancement in green roofs design to include an eco-roof with at least 70% coverage	2005
	Vancouver	Eco-Density	Building green liveable and affordable Communities	Cities' densification systems	2006
	California	California Global Warming Solutions Act of 2006(5)	Reduce GHG emissions in the state to1990 levels (25%) by 2020, and 80% below 1990 levels by 2050		2007
	Seattle	Green Factor	New developments in commercially zoned areas must commit 30% of the parcel area to urban landscaping	Attempts to account for various types of ecologically effective or environmentally friendly green systems	2007
Three dimensional	Singapore	Green Plot Ratio	Greening the buildings in cities	Sum of total leaf area developed in the site divided by the site area. Better correlation with the environmental performance of greenery	2003

3.1 AREA OF STUDY

Madurai is the oldest inhabited city in the Indian peninsula and is referred as Kadambavanam (forest filled with kadamba trees) at the banks of river vaigai. Madurai city has an area of 52 km², within an urban area now extending over as much as130 km², and it is located from 9°56′N to 9.93°N Latitude and from 78°07′E to 78.12°E Longitude. It has an average elevation of 101 meters above mean sea level. The climate is hot and humid, with rains during October to December. Summer temperatures range between 40 and 26.3 degrees Celsius. Winter temperatures range between 29.6 and 18 degrees Celsius. The average rainfall is about 85 cm and the average humidity is 65%.

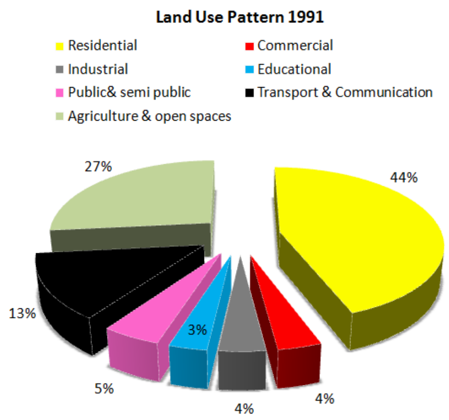

Figure 1 Land use pattern

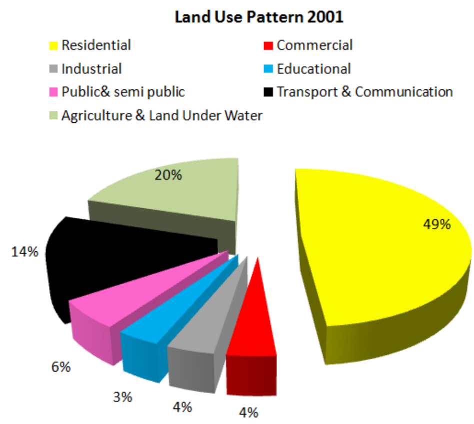

Figure 2 Land use pattern

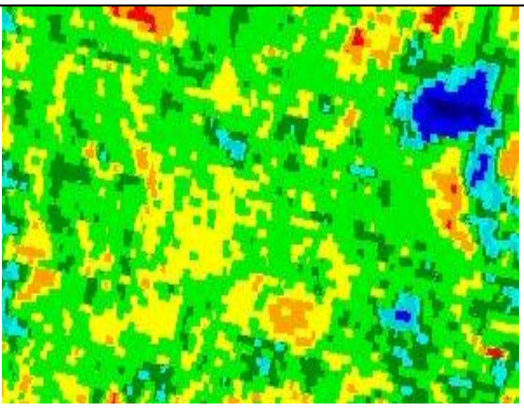

Figure 3 LST in 1991TM image. Source - Author

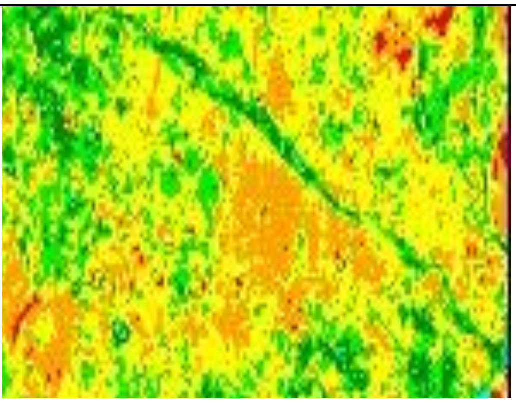

Figure 4 LST in 2001 ETM+ image. Source - Author

The impact of green spaces on the urban heat isalnd is more comprehensive if supported by the appropriate green space factors. The urbanization in Madurai has rapidly increased and has also increased land surface temperature of Madurai since 1990 to 2001. To substantiate this, study has been done with Land use patterns for 1991 and 2001 (Figure 1&2) and land surface temperature maps (Figure3&4) were prepared by using 1990 TM image and 2001 ETM+ image. Land surface temperature type indicates; "red and orange" with average temperature of 43.9°C and 41.9°C respectively for urbanized area a with a greater density of buildings and paved surfaces that absorb and retain heat from the sun, "yellow" with average temperature of 38.9°C for urbanized area a with a medium density of buildings and paved surfaces that absorb and retain heat from the sun, "green" with average temperature of 36.9°C for urban green areas, and "blue" with average temperature of 30.9°C for water bodies. This map shows that urbanization has spread rapidly from year 2001 especially in the central business district of Madurai. This rapid urbanization has contributed to the increase of urban temperature in Madurai. This map also shows how extremely green spaces are replaced by the grey spaces without considering the impact of huge loss of green space to the urban environment. Therefore, this study has examined the potential of green space factor in modifying the microclimate. Urban neighbourhoods was selected with dense (Study area 1 – Railway colony) and sparse vegetation (Study area 2 - Periyar) as shown in Figure 5 and compared with hypothetical conditions with mentioned scenarios and has been studied for their microclimatic performance is studied using micro scale model ENVIMET (4) due to its advanced approach on plant atmosphere interactions in cities. The numerical model simulates the complex urban structures with resolution between 0.5m and 10m according to the position of sun, urban geometry, vegetation, and soil by solving thermodynamic and plant physiological equations

Figure 5 Study areas. Source: Google Images

3.2 Model and its validation

Envi-met Version 3.1 (Bruse 2013) has been employed to simulate the potential impact of urban form and vegetation on the urban microclimate for March 20, 2014, during mid summer day when peak temperature is experienced. Envi-met is a three dimensional computational fluid dynamics and energy balance model that simulates plant air interactions in urban environments with a typical horizontal resolution of 0.5m to 10m in space and 10 seconds in time for built environment from microclimate scale to local climate scale at any location. Although Envi-met mainly uses a 3D prognostic model, it also uses 1D models to transfer all data input for wind speed, wind direction, air temperature, relative humidity, specific humidity and turbulence quantities (Bruse 2004). In order to conduct the simulation, basic data about the location, cloud cover conditions, initial temperature, wind speed at 10m above ground level, specific humidity at 2500m and relative humidity at 2m are required. In addition, the initial temperature, soil temperature (at 0m-0.2m, 0.2m-0.5m, 0.5m-2m), heat transmission in walls and roofs of buildings can also be defined in the mentioned model. The model gives a large number of output data that include air temperature, surface temperature, wall temperature, long wave radiation, shortwave radiation, latent and sensible heat fluxes, PMV, PPD, and MRT as the indicators of outdoor thermal comfort. In order to achieve realistic results, a simulation of an existing urban area in Madurai was carried out and the results were compared with on-site measurement temperature (1300LST on 20th March 2014) as shown in Figure 6. Envi-met was carried out for a 24 hour period starting at 0600LST with model output for every 60 minutes, using the configuration parameters. The relationship of both results was found to be correlated with an R-squared value equal to 0.876 (Figure 6). The verification process further rationalizes the use of ENVI-met to study the microclimatic issues in Madurai with hot and humid climatic conditions.

4 RESULTS AND DISCUSSIONS

Envi-met simulation was conducted for both the selected areas and the results reveal that the green spaces play a major role in modifying the microclimate.

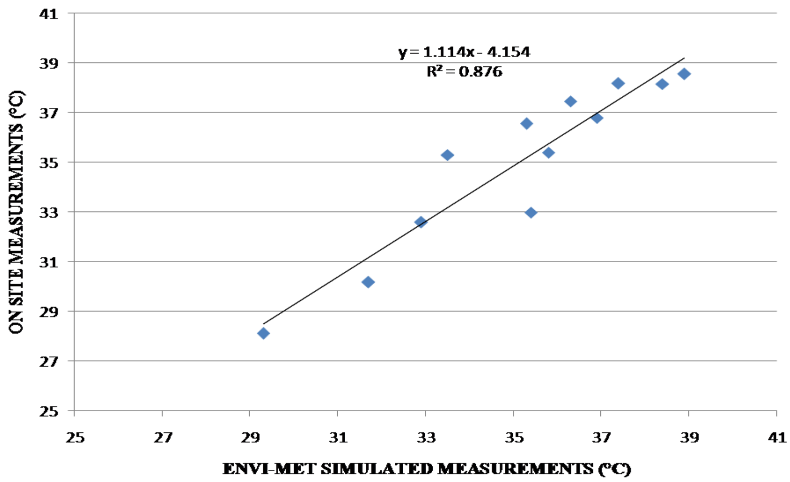

Figure 6. The relationship between ENVI-met simulation temperature and onsite measurement temperature (1 pm on 20th March 2014).

4.1 AVERAGE AIR TEMPERATURE

Figure 7 shows the average air temperature for different scenarios such as (i) with existing base case, (ii) nil vegetation, (iii) with turfs and (iv) with trees. Figure 8 shows the average air temperature for different scenarios such as (i) with existing base case, (ii) nil vegetation, (iii) with less number of trees and (iv) with increased number of trees since providing turf or lawns is not possible in this case as it has dense urban pattern with wall to wall construction.

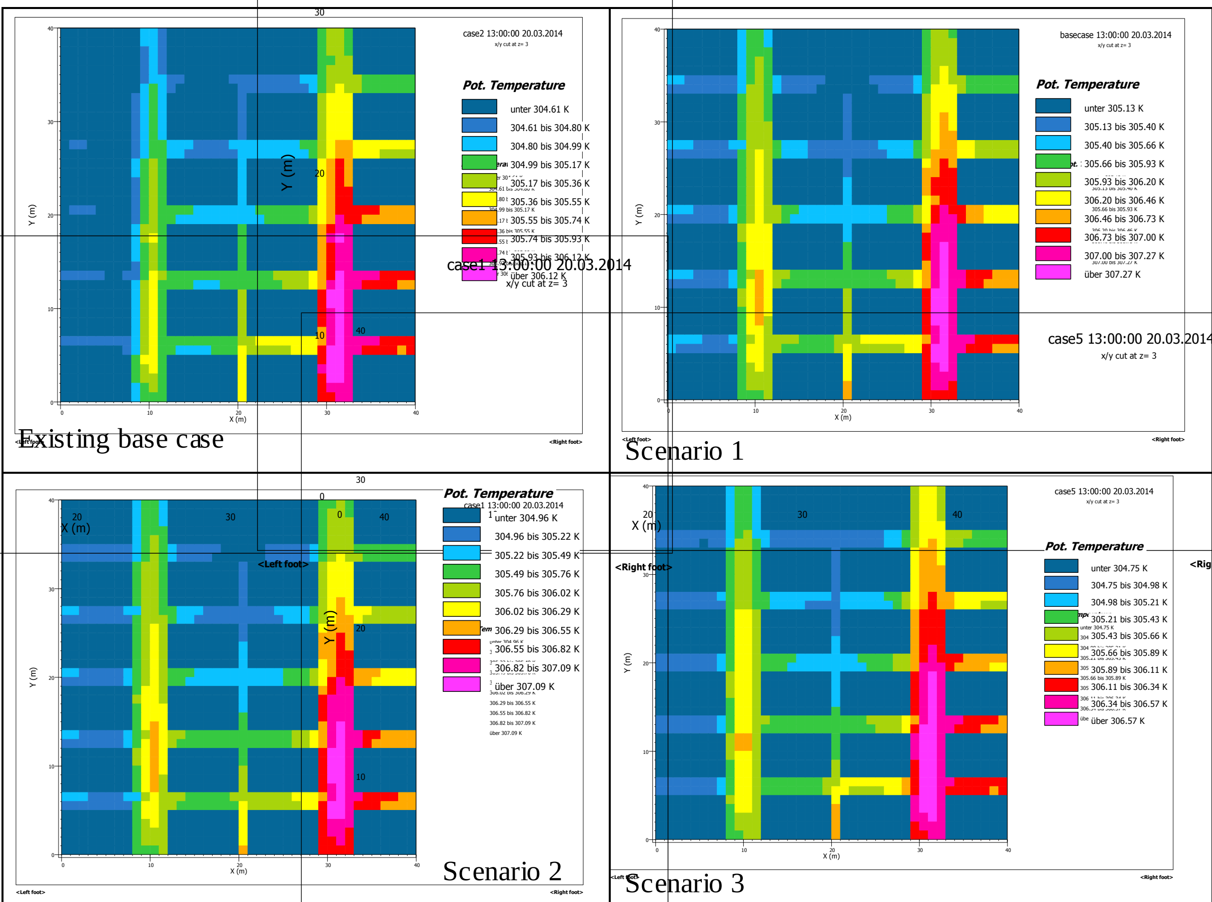

Figure 7 Air temperature for different scenarios for study area 1

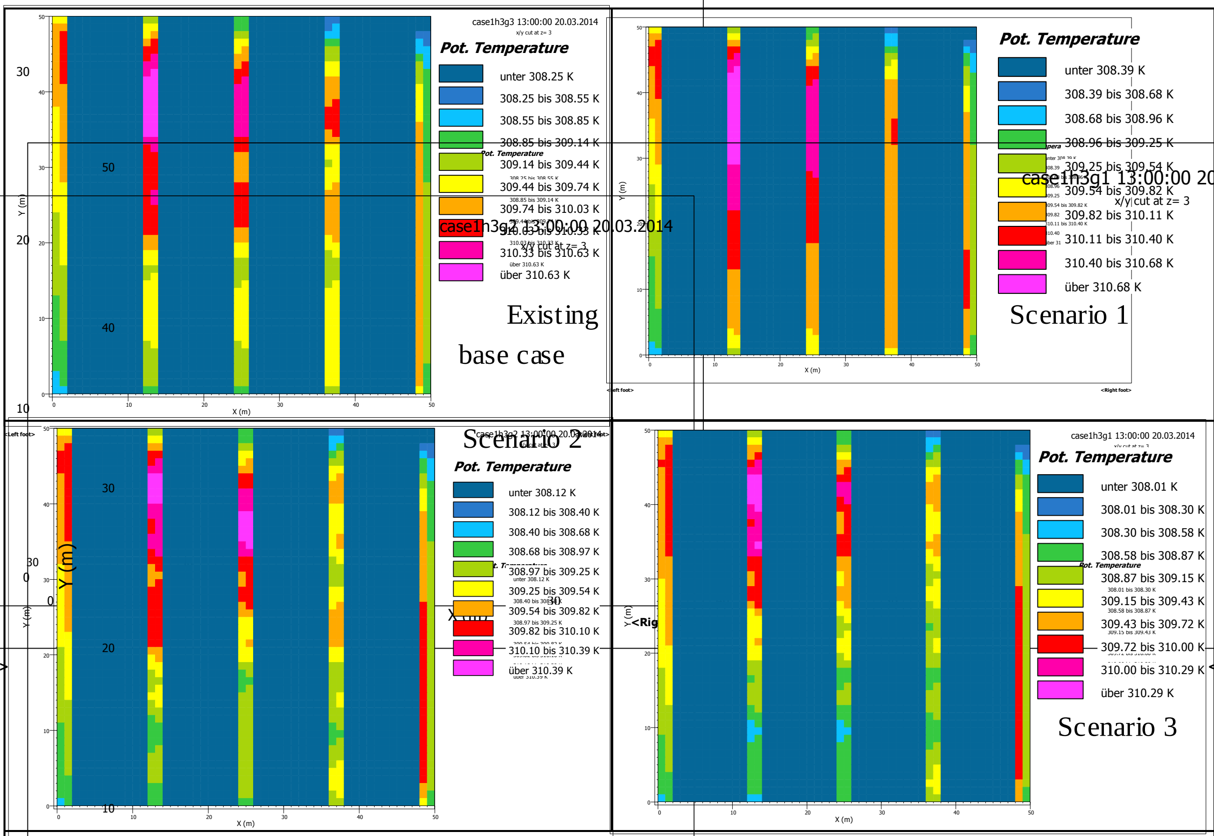

Figure 8 Air temperature for different scenarios for study area 2

4.2 APPLICATION OF GREEN SPACE FACTORS

Green plot ratio (GnPR) by Ong (2003) was known as an effective green assessment method to determine the ratio of green space distribution. According to Ong (2003), the GnPR has been defined as the average leaf area index (LAI) of the greenery on the site and also can be equivalently defined as the ratio of the total single-side leaf area of the planted landscape to the plot or site area. GnPR can be define as the area-weighted average LAI of a site, which account for unequal amount of area occupied by different plants in a landscape. Leaf area index can be defined as one-sided area of leaf tissue per unit ground surface area where the green plot ratio is the only green assessment method that relies on LAI.

For the selected sites, the green plot ratio (15) has been applied and simulated alongwith initial onsite observation which was conducted on 20.03.2014 for the climate monitoring and the plant distribution was accounted. This on site observation was only focused on the study areas, Madurai and during the observation the temperature found to be 31°C with clear sky conditions.

In this study the green plot ratio have been considered for all the scenarios as shown in equation 1. The green plot ratio have been carried out as following; existing base case, scenario (i) with no vegetation of 0 green area factor, scenario (ii) with lawn of green factor 0.304 and scenario (iii) only trees of green area factor 0.304 had impact on the reduction of temperatures. The calculations, assumptions, and results were given in Table 2 and 3.

Based on the understanding of the parametric study and Green space factor, the following key observations were found as given in Figure 7 and 8 which can be useful for urban planners.

First, greening is beneficial in cooling the urban environment and creating better urban microclimatic conditions for human activities at the ground level.

Second, tree planting is more beneficial than turfs or lawns (where trees provide shade for the lawns, to other vegetations and buildings) as evident from the study.

It also suggests that the green factor of above 0.45 is essential to reduce a maximum of 2°C in the built environment. Whereas in the study area 2 the temperature is reduced a maximum of only 1°C.

This also shows that the green factor of maximum 0.34 is not sufficient as it reduces about only 1°C and green factor of above 0.45 is as essential as to reduce a maximum of 2°C in the built environment.

Table 2.Green plot ratio conditions and ENVImet parametric results for study area 1

	Existing Base Case Recorded with outdoor weather monitoring station.	Existing Base Case Simulated with Envimet	Scenario 1	Scenario 2	Scenario 3
Total site area	12800	12800	12800	12800	12800
Total landscape area	6000	6000	NIL	1950	3900
Trees	40	40	NIL	NIL	25
Palms	NIL	NIL	NIL	NIL	NIL
Shrubs	NIL	NIL	NIL	NIL	NIL
Turfs	NIL	NIL	NIL	1950	NIL
Green Plot Ratio	0.468	0.468	0	0.304	0.304
Average Temperature found byENVImet	32.67°C	32.87°C	34.02°C	33.84°C	33.32°C

Table 3.Green plot ratio conditions and ENVImet parametric results study area 2

	Existing Base Case Recorded with outdoor weather monitoring station.	Existing Base Case Simulated with Envimet	Scenario 1	Scenario 2	Scenario 3
Total site area	10000	10000	10000	10000	10000
Total landscape area	1440	1440	NIL	2640	3600
Trees	6	6	NIL	11	15
Palms	NIL	NIL	NIL	NIL	NIL
Shrubs	NIL	NIL	NIL	NIL	NIL
Turfs	NIL	NIL	NIL	NIL	NIL
Green Plot Ratio	0.144	0.144	0	0.264	0.36
Average Temperature found byENVImet	37.8°C	37.98°C	38.1°C	37.54°C	37.24°C

5 CONCLUSION

Design strategies for open spaces and landscape in a site development not only require to accommodate their density in the site development standards, but also it plays an important role in modifying the microclimate and create thermal comfort since it controls the access of sun, light and wind. The microclimatic effect of the Green area factors were done with Envimet Numerical model. This has been done considering only the lawns and the trees. The results shows that trees perform better then the turfs or lawns. This lead to further investigate and develop green space factors for the thermal comfort conditions outdoors, based on the empirical data and numerical modeling. This Green space factor when included and applied in Madurai will help the Urban Designers, Planners and Landscape architects to decide on the percentage of green space to be included in the city which can create comfortable environment even in the urban neighbourhoods which is now available in the large urban open spaces such as parks alone. This further helps to reduce the UHI in the city which in reduce the energy consumption in the buildings.

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The UK's experience in mitigating climate change: a planned strategy or a learning curve?

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ABSTRACT

Reducing the CO2 emission by 80% from 1990 level by 2050 is a challenging operation for the UK. This challenge has embarked the whole nation in a national exercise that involves professionals in all sectors, corporations, SMEs, families and individuals. The nation meets every day with new tasks, initiatives and incentives designed to meet that target. The built environment is one aspect of this multi-faceted exercise and within the built environment itself many aspects are being tackled. This paper evaluates the current legislations, initiatives and incentives introduced in the UK to reduce the energy demand in the Built Environment and how they contribute to meeting the UK's international obligation in cutting CO2 emission.

Incentives such as feeding tariff for renewable energy, Green Deal for upgrading buildings and many other initiatives; have been withdrawn, revised or replaced after their excessive success or unexpected failure. These actions reflect the lack of clear plan and strategy. This paper won't examine the reasons of these success or failures but will use these disruptions as a call for the establishment of serious tools and mechanisms as a platform for discussion in mitigating climate change. Although the theme of this conference is dedicated to developing world, we believe that exchanging our experiences will benefit developing countries in avoiding our mistakes and follow successful steps. There is certainly no benefit in re-experiencing same failures as the world is embarked in the same climate change mitigating exercise.

INTRODUCTION

The climate change is monitored very closely by the IPCC (Intergovernmental Panel on Climate Change), whose main task is to review and assess scientific and socioeconomic data produced globally in order to understand climate change and in particular the effect of human activity on climate change (Ipcc.). Although there is evidence of the changes in global climate in the last 10.000 years, IPCC's reports show a significant rate of increase since 1750. A date that coincides with the industrial revolution (Pearson & Foxon, 2012) which has involved intensive use of fossil fuel to run ambitious industrial ideas and increase productivity (Antràs & Voth, 2003). Since then, an ever increasing large-scale production to satisfy booming economies and people's desire to maintain a comfortable level of living standard has worsen the situation of the planet's climate.

The global warming has entered the public domain after serious research undertaken in the 1950s when scientists began assessing the CO2 effect on climate change worldwide. The sad news resulted in the whole world engaging in long debates on how best to mitigate climate change. These debates took place between governments as well as nongovernmental organisations and resulted in solutions that were interpreted by each participating country, in different ways. The goal was to reach an optimum level of CO2 emission in the atmosphere while keeping industrial and socio-economical activities moving forward to meet people's needs and expectations in a sustainable manner (Momtaz, 1996).

The aim of this paper is to present the various initiatives introduced in the UK to mitigate the effects of the built environement on climate change as well as to evaluate their effectiveness. This investigation will show that some of these initiatives are rushed which is evidenced by the fact that many of them were withdrawn or revised shortly after being introduced.

THE UK AND ITS COMMITMENT IN MITIGATING CLIMATE CHANGE

The UK as many nations started organising itself to deal with climate change throughout conventions, agendas, road maps and declarations. Le country took swift actions and made significant commitments in response to these climate change (Department of energy and climate change. May 2014).

We have to bear in mind that, despite the CO2 emission worldwide being multiplied by three since 1990, the UK are still referring to the 1990 levels in their commitment to reduce the CO2 emission by 80% by 2050. Nonetheless, even such commitments require legal and technical instruments to be honoured.

In the Built Environment, various instruments have been created to reach that goal; these instruments varied from legislations to personal initiatives where the awareness was a major driver in finding alternative solutions to tackle climate change.

THE UK MAJOR ENGAGEMENT ACTIONS IN MITIATING CLIMATE CHANGE

The UK signed international agreements and reflected on them nationally put in place policies to reduce greenhouse gas emissions relatively early as part of the international efforts to limit global warming and other effects of human induced climate change. It now has a range of measures and targets in place, underpinned by statute, to achieve the reductions and in this regard has been one of the leaders internationally. As stated by the CCCEP (Centre for Climate Change Economics and Policy): "CO2 emissions are the main focus of climate change mitigation policies in the UK as they account for around 80% of total greenhouse gas emissions".

However whilst the UK may claim, with some legitimacy, to have been at the forefront of measures and policies to tackle climate change it is less clear how effective those measures and policies have been, or indeed what the likelihood is of achieving the ambitious target of an 80% reduction in carbon emissions by 2050.

According to The Energy Saving Trust, in order to 'achieve these goals the UK needs radical change' (Energy saving trust, 2014). A report on the UK's climate change policy, in 2011, by the CCCEP concluded that 'a step-change in the pace of emission reductions is required to put the UK on the path towards its ambitious 2050 target' (Climate change policy in the United Kingdom, 2014).

Since the UK government passed the Climate Change Act in 2008 to impact positively on climate change, this long term legally binding framework requires the reduction of the UK annual carbon emissions to 154.2 million tonnes of CO2 by 2050.

To reach such level of CO2 reduction, the British Governments introduced a number of regulations and incentives at various levels. These regulations were not necessarily based on a quantitative analysis and scheduled intermediate aims based on capabilities to meet the set target. Selected regulations and incentives are shown next and vary between successful unchanged regulations to multi-updated incentives.

UK ACTIONS TOWARDS REDUCING CO2 IN BUILDINGS AND THEIR REVISIONS

1. The introduction of the Energy Performance of Buildings Directive (EPBD) in 2003 which influenced the construction industry and building renovation. However, this measure can be challenging given that the buildings' actors need to look for different means to reduce the building energy consumption and require the exploration of a huge number of possible combinations of energy-saving measures. (Hamdy, Hasan, & Siren, 2013). A recast took place in 2010 followed in 2013 by a proposal from the Scottish Government to consult on the implementation. A new change took place in 2013 as a result and the green Deal took place (Scottish Government).

   The Government introduced SAP (Standard Assessment Procedure), a method which aims to calculate and assess the overall energy use of buildings. Although this method of assessment didn't go through revisions and changes, its formulation was not practical for all buildings. This method was criticised at various levels, it still has its importance in energy use assessment of dwelling, but still controversial (Kelly, Crawford-Brown, & Pollitt, 2012). SAP calculation is a requirement to demonstrate compliance with the energy performance requirements of Part L of the Building Regulations, as well as used to demonstrate achievement of the required performance levels for sustainability benchmarks such as the Code for Sustainable Homes.

2. Building Regulations Part L (Conservation of Fuel and Power). Provides guidance on the means to comply with the energy efficiency requirements of the Building Regulations. It deals with a number of areas including insulation requirements, heating and air permeability etc. but also sets out the requirements for SAP calculations and Carbon Emissions Targets for dwellings (Planning portal, 2014). The reinforcement of the existing Building Regulation in its Part L dedicated to the energy performance. This continuously updated regulation has seen a huge step forward in regards to the minimum energy performance requirement of new buildings and refurbished existing buildings. The requirements, expressed in U-Val, are not generic to the whole building but very specific to the building's components such as the roof, wall, windows and floor.

3. The Building Regulations co-exist with other standards and recommendations that largely relate to best practice (Department for building innovation and skills, 2014), for example BREEAM and the Code for Sustainable Homes. BREEAM is an environmental assessment method and rating system for buildings which, amongst other key areas of environmental impact, addresses energy demand, consumption and CO2 emissions by promoting designs that minimise demand and consumption in buildings thus reducing carbon emissions. These instruments have been in place early enough to influence the building sector by reaching the whole building sector industry and achieve thereafter part of the goal.

4. The Code for Sustainable Homes is in effect the domestic version of BREEAM and there remains to date a mandatory requirement for new homes to be rated against the Code. However in an effort to reduce 'red tape' in the housing construction industry the government has confirmed, in March 2014, that it will be 'winding down' the Code and consolidating some of its requirements in the Building Regulations (Sustainable construction legislation, regulation and drivers, 2014).

5. The Feed-In-Tariff was announced in 2008 and introduced in 2010 to replace the UK Government grants as the main financial incentive to encourage uptake of renewable electricity generating technologies. Less than a year into the scheme, the new coalition Government announced that support for large-scale photovoltaic installations would be cut. From August 2011 the rate for installations changed. In October 2011a second review of the Feed in Tariffs for low carbon electricity generation was announced and was supposed to take an effect from 12th December 2011. In its second year, the government announced further cuts to the FIT scheme. On 5th March the tariff was cut done. This cut was originally scheduled for 12th December 2011 but was delayed. The latest cut came into effect on 1st November and this rate was set to remain until 1st February 2013). Another drop in the FIT is to take place in January 2015 to £0.13 that is a 1/3 of its original incentive of £0.43. This can't come from a strategic approach infortunatly.

6. Energy Performance Certificates (EPC) is a Post construction monitoring tool, reporting on energy efficiency of building of small scale. The buildings are then classified into categories from A to G where A indicates the best rating. EPCs are mandatory for the sale and letting of properties but they provide only theoretical ratings on energy performance based on the design and construction in conjunction with assumed patterns of use and occupation. Such theoretical assessment doesn't convey a full understanding of buildings and a more measurable approach are required to really have a clear perception of these buildings. Further collaboration between energy supply companies to provide buildings' energy consumption might give a better understanding on where these building stands in regards to their CO2 emission but not on their heating need therefore separated meter for heating and cooking where possible will narrow the potential misleading analyses given by the EPC.

7. The Display Energy Certificate (DEC) (Display energy certificates, 2014) is more of a permanent document to display. They are far more informative with regards to energy performance as they are based on actual consumption but despite the fact that there is evidence that their use can help achieve substantial reductions in energy use they are currently only a requirement for buildings that are over 500m^2 and occupied by the public sector (Fuerst & McAllister, 2011). There is more of a psychological influence on occupants to save energy but might not be effective in long term if actions are not taken forward.

8. The compulsory inspection of equipments, such as boilers, to insure their performance. This is an important measure given that 57% of energy use in the UK goes towards space heating. However, the guidelines did not insist on the best performance at this stage but a new future enforcement is due to take effect where buildings will be assessed to that level. As a consequence, many landlords might find themselves not able to rent out their properties if they don't meet certain levels of performance. (Hamilton, Steadman, Bruhns, Summerfield, & Lowe, 2013). This level of performance, although known, is still unclear on how to be reach in efficient way.

9. The Green Deal was included in the Energy Act 2011 and came into force in 2012. In 2014 a second green deal would be launched, as grants rather than the loans which underpinned the original Green Deal scheme.
   The initial Green Deal didn't take into account a socio economical and behaviour of home buyers since the deal consisted on a loan to be granted and remain with the property rather than with the initial owner, hence its failure. The Green Deal is a government initiative to try and incentivise building owners and occupiers to invest in improving the energy efficiency of existing properties by offering 'green finance' for the installation of energy efficiency measures. Taken at face value a scheme that offers the chance to fund improvements to the energy efficiency of property with the promise that the savings will outweigh the cost of the finance (the so-called 'Golden Rule') appears attractive and an effective way of targeting a big contributor, housing, of carbon emissions.

   The reality has been somewhat different with doubts over value for money (uncompetitive interest rates for the loans offered) as well as little, and often conflicting, evidence to support the government's assertion that the investment is financially worthwhile (for the occupier). Uptake to date has been very low and the initiative is plagued by the perception that neither energy companies nor the government are committed to the scheme.

   The Green Deal is an attempt to deal with the retrofit of energy efficiency measures in existing homes which is clearly is a key area to target but its apparent failure suggests the strategy is not working in its current form.

10. The GCB was set up to provide leadership to the sector on reducing carbon emissions and capitalising on low carbon growth opportunities, as well as monitoring the implementation of, actions in the Low Carbon Construction Action Plan. It was announced in February 2014 that the Green Construction Board (GCB) will continue its work on reducing carbon emissions for a further two years. The focus of the GCB over the next two years will be working towards delivering the 'ambition of a 50% reduction of greenhouse gas emissions by 2025'. It will be interesting to see what recommendations are made to achieve the 'ambition target' of 2025 that will act as benchmark for the 2050 commitment.

The above list can be extended to other actions and strategies however the message is conveyed through these actions and showing the coutry's 'rush' to demonstrate many actions towards 2050 target. Although all actions are positive in their contents, the wider vision doesn't seem to be that positive. The fact that these actions were addressed short after their applications and this reflects a quick response and therefore a close monitoring of the outcomes. Were these actions put in place for just testes? Something we won't know from diferent governements in place since?

BUILT ENVIRONMENT AND CLIMATE CHANGE

The Royal Institute of British Architects (RIBA) describes the UK government's overall strategy as 'encouraging organisations to reduce their emissions and embrace opportunities through setting regulations, establishing market-based mechanisms, providing incentives and ensuring the provision of information, advice and support'. It [the government] hopes that in doing this it will 'help to stimulate development of low carbon solutions and services and promote their uptake within the UK' (Willars, 2014).

The UK Green Building Council quotes: Construction and Sustainable Development report that states that 'energy from fossil fuels consumed in the construction and operation of buildings accounts for approximately half of the UK's emissions of carbon dioxide' and 'housing alone generates 27% of UK emissions, of which 73% is used for space and water heating' (Constructing Excellence, 2008). This means that space and water heating in UK homes is responsible for nearly 20% of the UK's carbon emissions.

Further evidence is found in the UK Government Department for Business Innovation and Skills 2010 report that estimated the amount of CO2 emissions that the construction industry can influence. It considered the life cycle of buildings from design, through operation to refurbishment/ demolition. It concluded that the industry could influence almost 47% of all the UK's emissions and in-use building emissions accounted for 80% of this figure (Department for building innovation and skills, 2014). Therefore building emissions in-use alone is estimated to account for over 37% of all of the UK's CO2 emissions.

It is not disputed that the built environment and the construction industry are major contributors to the UK's carbon emissions and therefore required to play a significant role in actions and strategies to meet the reduction targets. In the UK the means of doing this is largely through the Building Regulations. The Building Regulations are the statutory instruments that are used to try and ensure that legislated policies are acted upon.

The UK has highly ambitious targets for 'zero carbon' standards but it remains unclear as to exactly what the definition of 'zero carbon' is or how it will be reached. The Code was introduced in 2006 to help achieve the pledge that all new homes would be 'zero carbon' from 2016 but its 'winding down' is part of a wider review and plans to 'rationalise all building regulations and national and local housing standards' (UK Green Building Council, 2014). The UK Green Building Council claims that not only was the 2016 Zero Carbon target instrumental in achieving improved environmental standards and innovation in building (UK green building council, new built.2014), but also that the changes now being made will 'almost certainly result in poorer quality homes, built to lower environmental and social standards' (UK green building council-government shake-up of housing regulations likely to cause confusion, affect quality and slow down delivery warns UK-GBC, 2014).

Inevitably, opinions differ on the motivations and likely impact on sustainability of the decision to phase out the Code. The decision is based on a desire to reduce 'red tape', and in the process help to invigorate the housing construction industry. This raises an interesting point that is a basic problem for governments in tackling carbon reductions. One of the biggest reductions in carbon emissions recently followed the 2007 recession and downturn in the economy and conversely a growing economy sees an increase in output and carbon emissions. A challenge for government is to stimulate and grow economies without sacrificing climate change targets. It begs the question of whether governments can be relied upon to balance long term climate change policies over other issues such as economic growth.

One of the key issues of this study is the energy performance gap: that is the difference between the designed performance and the actual in-use performance with regards to energy efficiency and consequently operational carbon emissions. It is interesting to note that the mandatory requirements for assessing energy performance prior to construction are based on theoretical performance and that the reporting on the energy efficiency of the vast majority of buildings once completed and in use is also based on theoretical assumptions rather than actual performance. A 2012 report that analysed actual energy use in commercial properties found 'little or no correlation between EPC ratings and actual energy performance' (Jones Lang Lasalle & Better Buildings Partnership, 2014).

THE ECONOMICAL IMPACT OF MITIGATING CLIMATE CHANGE

The move to the low carbon economy cannot be without an impact as stated by Sir Nicolas Stern, who highlighted, in a world renowned report, the dramatic consequences of not acting and insisting that the economical impact of not acting is worse than acting: "The costs of stabilising the climate are significant but manageable; delay would be dangerous and much more costly." (STERN, 2007). We should emphasise that the economical aspect of mitigating the climate change was of concern at an early stage of the climate change debate. Although nations have different financial capabilities, they, nonetheless, face the same challenge. Such financial disparities were addressed in later climate change discussions and encouraging solutions where found to make it less challenging for developing countries. This was introduced in the form of CO2 trading mechanisms involving developed and developing nations as stated by the United Nation Framework Convention on Climate Change (UNFCCC) 2014).

DISCUSSION AND CONCLUSION

The concerns raised in this paper appear to be fairly consistent in saying that:

- There is a lack of clear understanding of the mechanisms and their capabilities in mitigating climate change in the UK. The withdrawn of certain initiatives based on their excessive success such as FIT was not particularly welcomed.
- Current legislation and strategies are insufficient, inconsistent and unclear from the operational perspective.
- The rate of progress needs to change radically if the UK is to have any chance of meeting its legally binding commitments by 2050. Meeting the target in advance is also problematic since this will be achieved against other needed development in the country.

In consideration of current observations and research it seems that some of the key areas of focus in order to achieve the government targets of CO2 reduction that require further investigation are:

1. Making DECs mandatory for all buildings so that the actual performance is measured rather than theoretical (predicted). DECs are also accompanied by an advisory report that identifies measures to improve the buildings' energy rating as currently there is no obligation to act on the advice in the report.
2. Legislation tends to focus primarily on new build properties. The biggest single contributor to carbon emissions from the built environment and construction is operational carbon from residential property (space and water heating) and the vast majority of dwellings (around 80%) that will be in use in 2050 have already been built. Therefore retrofit should be the main focus to reduce in-use operational carbon emissions.
3. The way the building occupiers behave and use their buildings is hugely significant in terms of energy consumption (and therefore carbon emissions), yet existing assessment methods such as SAP ratings and EPCs are not able to account for the complexities and variations that accurately reflect how significant occupant's behaviour is.
4. The government needs to increase its efforts to incentivise people and organisations to want to make their buildings more energy efficient. A small percentage will pursue a low or zero carbon building because of an ideology or ethos but the majority will respond more to legislation and/ or financial incentives.
5. The revisions of many initiatives including legislations and incentives the UK saw in the last decade reflects a clear uncertainty in regards to the effectiveness of what is made in place to mitigate climate change.
6. There is still a lack of strategy to quantify and measure the potential outcomes of these initiatives hence their suspension or revision.
7. There is not enough measuring of the actual performance and too great an emphasis is placed on the theoretical or predicted performance based on design assumptions.
8. Not enough is done by the government to make it easy and cost effective for building owners and occupiers to implement energy efficiency measures in existing buildings with an over reliance on 'encouragement' and 'hope' that the market will develop low carbon solutions that are taken up to 'solve' the problem.

It is understandable that a start needed to happen to mitigate climate change but the lack of expertise worldwide has led to a period of trial and error. This period lasted for more than it should and the time has come for actions based on strategies and undertaken by experts in consultation with all stakeholders. Actions should be seen in a wider context and overseen by multidisciplinary teams to anticipate dysfunctions that can happen along the way as was stated in this paper.

This period of trial and error was certainly costly, time and cost wise. This lost won't be passed on to other nations who joined lately the mitigating climate change actions. PLEA is certainly the hub where experiences are exchanged to move on from trials actions to planned strategies.

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Energetic expenses of walls and roofs used in the metropolitan zone of Tampico, Madero and Altamira

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ABSTRACT

This is a presentation showing the procedures and results obtained from the analysis of the energy transmitted in walls and roofs of the selected homes in the south zone of the state of Tamaulipas, one of the five zones established in the "Development and validating of a methodology to estimate the impacts in the saving of energy for the use of passive-constructive systems in the edification for different climates in México" project, which third stage of execution's objective consisted in making use of the Ener- Habitat software, developed during the project's second phase. This research was sponsored by the Energy Sector Sustainability Fund SENER - CONACYT S0019 - 2009-01 call log under the project No. 118665. With this software the comparative energy expenses of four constructive systems for walls and three constructive systems for roofs were determined. With the acquired information and through the use of the methodology developed to estimate the impacts on energy saving, the energetic price of each of the constructive systems was evaluated. With the acquired results it was determined which were the walls and roofs of less energy expense for the study zone.

INTRODUCTION

It is essential in locations which have high solar insolation and large temperature variations through the day to evaluate the thermal performance of building systems. This emphasizes G. Barrios, P. Elias, G. Huelsz and J. Rojas (2010) who state that "in climates where solar radiation is significant and the daily temperature swing is important, as in most of Mexico, the heat transferred through walls and roofs must be analyzed as a function of time. For these climates, the steady state heat transfer model from a period of time can lead to the improper selection of materials".

The objective of this project is to provide guidance for the selection of suitable constructive systems for the warm-humid climate of the southern part of the state of Tamaulipas to help improve the thermal comfort inside the home without using air-conditioning systems.

The study was divided into three parts:

A. Apply the methodology established in the project protocol .

B. Analyze the results derived from the Ener - Habitat program[1] construction systems of the

[1] For further information consult: http://www.enerhabitat.unam.mx/Cie2/

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selected walls and roofs, comparing energy costs.

C. Get the conclusions of the investigation in the study area.

This also implied a review of climatic factors existing in the study area formed by the municipalities of Tampico, Madero and Altamira, prevailing therein a warm-humid climate with average summer temperatures of 29°C in summer and 21°C in winter. The variations of weather through the year fluctuate in summer ± 10°C and in winter ± 8°C.

METHODOLOGY

As part of the established objective, the following steps to define the selection of constructive systems for the warm-humid climate of the study zone were generated.

A. Twenty five housing buildings were selected in the south zone of Tamaulipas for investigation.

B. A data sheet designed to provide the information of each of these homes on their behavior with regard to the thermal comfort inside, provided the m2 of property, the square meters of construction, typology, orientation, vegetation and exterior colors.

C. Determine which passive systems impact on each housing building.

D. Analyze the constructive systems of walls and roofs using the software. Ener-Habitat solves the time dependent one dimensional heat transfer equation using the sol-air temperature at the exterior. At the inside, the indoor air temperature can be assumed constant (air-conditioned) or as a function of the heat transferred through the constructive system (free running).

E. Compare, using the Ener- Habitat software, the two most widely used construction systems in the area which transmit less energy for walls and roofs.

F. Suggest other systems of walls and roofs in different layers, so as to establish the best benefit cost.

G. Different layers of walls and roofs were proposed which were analysed for their energy-cost with the information provided by the Ener-Habitat software.

H. Determine which were the final layers of walls and roofs of lower expense and energy-cost of the climatic zone of study.

RESULTS

With the information gathered in the data sheets of the 25 homes tested, it was determined how passive systems impacted in each of these homes .

It was shown on a study which were the constructive materials for walls and roofs more widely used. This information was used to feed the Ener-Habitat software which steps are:

I. Select the construction system (wall or roof). Determine whether the layers are homogeneous or not and understanding that homogeneous are those with a single material and no air gaps.

II. The following information is selected from the database:

   a) The city where the calculation will be made: in this case Tampico.
   b) The time period analyzed: annual or a specific month.

c) Use of air-conditioning: yes or no.

d) Select the tipe of construction element: roof or wall.

e) Number of building elements to compare: 1 to 5.

III. Determine the amount of building elements to be analyzed, for all the following (Image 3):

a) Orientation: north, south, east, west, other.

b) Tilt angle: 0º to 90º.

IV. The layers of the construction system from 1 to 7 are introduced to be analyzed

V. Determine the absorptance, the thickness and the material of the outer layer of this system. And subsequently, determine the thickness and the material of the following layers. Because the time dependent heat transfer equations are solved, being the thermal properties needed for the evaluation the thermal conductivity, the density and heat capacity, as well as the width of each layer.

VI. Finally, after entering all the data, the software shows the results from the Ener-Habitat through tables and graphics .

Image 1. Selection of layer material.

The calculation of the energy transferred to the two different wall construction systems to compare the walls and roofs of the building envelope used in the area of Tampico was made considering that all the walls are west facing. This was done in order to compare them regardless of orientation.

In Table 1, the two types of walls most used in the zone are shown. Percentages of the construction systems used in homes as well as the transmitted energy values are included. Each system has two extreme values of transmitted power; the minimum value corresponds to the wall that transfers the least amount of energy and the maximum value corresponds to the wall that transfers more energy, classified within the same type.

Furthermore, the values of energy transmitted in the same type of construction system presented in Table 1 are associated with walls with clear exterior colors, which have low solar absorptance (A). Without air conditioning, it is observed that the energy transmitted by the walls with no homogeneous layer (wall of hollow concrete block) is 2.56Wh/m^2 day. This allows us to affirm that the walls with no homogeneous layers and more space between their inner sides are more suitable for homes without air-conditioning operating in southern Tamaulipas.

The calculation of energy transmitted in the walls north, south, east and west to find the best orientation and also using white colors with absorptance 0.1 was found to be the most used in the building systems in the area.

The most energy transmitted is from the wall facing west with an average of 4.80Wh/m2 per day and the wall with less energy is facing east with an average of 3.62Wh/m2 per day and therefore being the best orientation for the zone.

Table 1. Result rates of transmitted energy in the wall construction systems.
Source: Created by researches with Ener-Habitat (2012).

Wall construction system	Label	% Construction systems	Without air conditioning Energy transmitted warmest month (Wh/m2 day)
Hollow concrete block 10cm	BH_acay_10	36.0	19.12
Hollow concrete block 15cm	BH_acay_15	64.0	2.56
Total non homogeneous construction systems		100	
Total housing represented		1325	

The best wall construction systems without air conditioning is using hollow blocks of 15cm with 2.56Wh/m^2 per day, in second place, with a bigger difference, is using hollow blocks of 10cm with 19.12Wh/m^2 per day.

The wall construction system non homogeneous to analyze the effect of color is shown in Table 2.

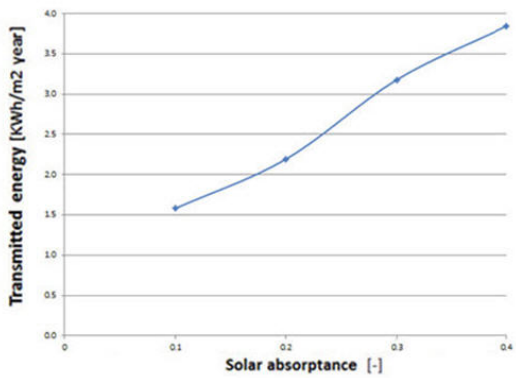
Table 2. Specification wall construction system used to study the effect of color.

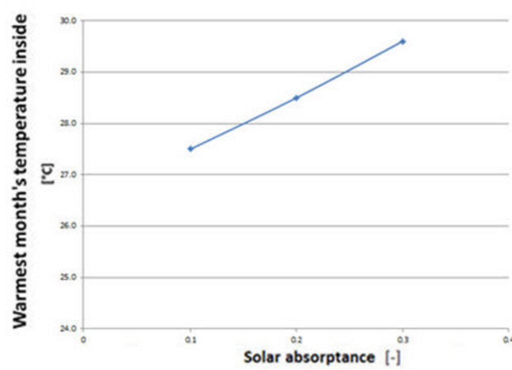
Construction system components (outer layer → inner layer)	**Thickness (cm)**
Sand-cement mortar	1.50
Hollow concrete block	15.00
Plaster	1.50

With the Ener-Habitat software solar absorptance varied from 0.1 to 0.7 without air conditioning during the critical summer month of August. The transmitted energy increases linearly with solar absorptance 0.4kWh/m2 per year for each 0.1 of solar absorptance, is shows in graghic 2.

The average interior temperature in the warmest month also increases linearly with the increase of solar absorptance as shown in figure 3. For A = 0.1 the average temperature is 27.5ºC, while for A = 0.3 is 29.6ºC. In this case, the increase is 1ºC for every 0.1 increase in solar absorptance. For this reason light colors are recommended in the outside of the walls, especially the west and eastern walls, which receive more solar radiation is shows in graghic 3.

The evaluation of energy cost, using the Ener- Habitat software, was conducted using horizontal roofs. Two types of homogeneous roofs were used, concrete ribs and polystyrene blocks of 10cm and 15 cm. The systems were evaluated without air conditioning.





Graph 2. Transmitted energy as a function of solar absorptance on the wall. Graph 3. Indoor-air-average temperature as a function of solar absorptance on the wall.

Table 3 shows the percentages of each type of construction systems used in homes as well as the transmitted energy values. The best rated roof construction system shows that the transmitted energy is of 8.55 Wh/m^2 per day. ||

Roff construction systems	Label	% Construction system	Without air condition Energy transmitted warmest month (Wh/m2 day)
Concrete rib slab and polystyrene block 10cm	NeCa_cfy_10	16.0	9.31
Concrete rib slab and polystyrene block 15cm	NeCa_cfy_15	84.0	8.55
Total non homogeneous roof construction systems		100	
Total housing represented		1325	

Table 3. Result Rates of transmitted energy in roof constructive system.
Source: Created by researchers with Ener- Habitat software (2012).

To calculate the cost-benefit of wall construction systems, three systems were used: the first system is a brick wall with an exterior and interior finish of sand-cement mortar of 1.5cm, the outer surface being white with a solar absorptance of 0.1; the second being a wall of compressed earth block 14cm thick, with an interior and exterior finish of sand-lime mortar 1.5cm with solar absorptance of 0.10; which mechanical behavior is shown in table 4. The third is a set of five layers, two layers of compressed earth block joined by a sand-lime mortar being the same used for the interior and exterior layers.

Dry condition		Humid condition	
% Dry cement	Resistance Kg/cm	% Humid cement	Resistance Kg/cm
6%	41.40	6%	41.40
8%	77.72	8%	44.63
10%	120.74	10%	44.63

Tabla 4. Mechanical behavior, compressed earth block.
Fuente: Roux (2010).

The analysis for the proposed wall construction system is to compare the cost-benefit factor that obtained from the product of the energy (E) for the cost (C) of the 3 proposed systems, taking care that the standard cost (Cu) is not too high.

Table 5 shows that "Wall One" transmits more energy (E=1.20) than the "Basic Wall", its cost is equal to the "Basis Wall" (C01.0), so that a cost- benefit factor is E*C=1.20. "Wall Two" transmits a fraction of energy E= 0.70, and has less cost than the "Basic Wall" (C=0.70) and the cost- benefit factor is E*C=0.49. "Wall Three" transmits less energy than the "Basic Wall" (E=0.10), the standard cost is C=1.10 and its cost- benefit factor is E*C=0.11.

"Wall 3" is the one with the lowest cost-benefit factor E*C = 0.11 and this cost is even higher than the basic system. Note that this type of construction system with double compressed earth block 32cm thick is not currently on the market in the area.

For the proposed roof construction system, the same methodology for walls is used.

"Roof One" is a conventional slab of reinforced concrete; while "Roof Two" has in addition a layer of polyurethane foam of 2.5cm of thickness. The two systems have an exterior finish of white acrylic waterproofing (absorptance of 0.20) and an internal plaster finish.

Wall construction systems	**α [-]**	**Layers**	**e [m]**	**Eu [Wh/m^2 day]**	**Cu [\$/m^2]**	**E* [-]**	**C* [-]**	**E*C* [-]**
Basic Wall	0.1	sand-cement mortar	0.015		85.8			
		hollow concrete block	0.150		151.6			
		sand-cement mortar	0.015		85.8			
Total basic wall			0.150	2.056	484.0	1.00	1.00	1.00
Wall One	0.1	sand-cement mortar	0.015		85.8			
		brick	0.160		143.0			
		sand-cement mortar	0.015		85.8			
Total Wall One			0.170	3.035	314.5	1.20	1.00	1.154
Wall Two	0.1	sand-lime mortar	0.015		40.0			
		compressed-earth block	0.140		140.0			
		sand-lime mortar	0.015		40.0			
Total Wall Two			0.170	1.90	220.0	0.70	0.70	0.50
Wall Three	0.1	sand-lime mortar	0.015		40.0			
		compressed-earth block	0.140		125.0			
		sand-lime mortar	0.010		40.0			
		compressed-earth block	0.140		125.0			

		sand-lime mortar	0.015		40.0			
Total Wall Three			0.320	0.375	370.0	0.10	1.10	0.168

Table 5. Comparison of wall construction systems in Tampico.
Source: Created by researchers (2013).

Table 6 shows that "Roof One" transmits more than twice the energy value of the "Basic Roof", with E = 2.4 which has a standard cost of C = 0.9 and a cost-benefit factor E * C = 2.16. "Roof Two" transmits a normalized energy E = 0.1, and has a cost of C = 1.0 as the "Basic Roof" with a cost-benefit factor E * C = 0.10.

Roof construction system	α [-]	Layers	e [m]	Eu [Wh/m^2 day]	Cu [\$/m^2]	E* [-]	C* [-]	E*C* [-]
Basic Roof	0.10	acrylic waterproofing	0.001		70.0			
		compression layer	0.035		650.0			
		polystyrene block	0.150					
		plaster	0.015		180.0			
Total Basic Roof			0.201	5.52	900.0	1.00	1.00	1.00
Roof One	0.10	acrylic waterproofing	0.001		70.0			
		reinforced concrete	0.120		540.1			
		plaster	0.015		180.0			
Total Roof One			0.136	13.06	790.1	2.4	0.9	2.07
Roof Two	0.20	acrylic waterproofing	0.001		170			
		polyurethane foam	0.025					
		reinforced concrete	0.120		540.1			
		plaster	0.010		180.0			
Total Roof Two			0.156	0.791	890.0	0.1	1.0	0.142

Table 6. Comparison of roof construction systems in Tampico.
Source: Created by researchers (2013).

CONCLUSIONS

The thermal performance of a house depends on many variables; most of them derive from the architectural design, especially, the morphology rather than the materials and construction systems; however the knowledge and use of thermophysical properties of materials is an aspect that can more easily be subjected to regulation. Some decisions regarding the selection of materials can contribute to the better performance of the building, particularly if the materials are appropriate to the environmental conditions of a region.

The study in the area has shown in its initial stages that the construction processes used for architectural housing envelop are not the most appropriate. So to continue analyzing and comparing these processes, it has been established that in the case of the walls, the compressed-earth block has a better thermal performance than the traditional hollow-concrete block used for building walls. For roofs, the results of the analysis showed that the lightened layers (polystyrene foam and reinforced concrete) are less efficient than the reinforced concrete with polystyrene foam.

For the south zone of Tamaulipas, where a warm humid climate prevails, the construction systems recommended without air conditioning are:

For walls, a double compressed earth block with a thickness of 29 cm and an outside and inside finish of sand-lime mortar 1.5cm thick using white exterior colors and a solar absorptance of 0.1 are proposed. The energy transferred from this construction system is 0.10 used and its cost is 76 % of the value of the most used in the zone, with a value of the cost -benefit factor of E*C=0.11

For roofs, a reinforced concrete slab of 12 cm with a layer of polyurethane foam 2.5cm on the top and a finish of acrylic waterproofing 1cm thick using white colors with a solar absorptance of 0.10 and in the interior a plaster of 1cm thick is proposed. The energy transferred from this construction system is 0.1% of the value of the most widely used in the area with a cost-benefit factor of E*C=0.10.

For the south zone of Tamaulipas, where a warm-humid climate prevails, the dwellers usually have mechanical ventilation, like air-conditioning, to improve the thermal confort.

The study showed that the construction systems proposed and mentioned above were efficient for thermal confort even without using air conditioning.

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Urban Physics for tomorrow's Urban Design

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ABSTRACT

The quality of urban life and urban experience is being compromised regularly in urban areas; one primary aspect being continuous urban climate degradation because of concentrated anthropogenic intervention in natural climate. As a result of rapid urban sprawl, drastic modification of the natural setup are common all around; like transformation of surface cover, alteration of watersheds and natural drainage, devastative destruction of natural flora and fauna, which in turn deteriorates the overall urban experience. On the other hand, urbanization is the necessity to sustain the economic growth and overall prosperity of the population in the present global scenario. Maintaining the quality of urban experience is one of the toughest challenges to the planners, urban designers and architects.

The researchers are investigating on the impacts of modified urban climate in terms of degraded air quality, thermal discomfort, unbalanced hydrological cycle, and various socio economic impacts as a result of the same. Urban physics is increasingly gaining importance in the research world as a tool to mitigate the urban climate and improve the overall living experience in urban areas. Urban physics is basically an inter-disciplinary approach combining physics, environmental chemistry, aerodynamics, climatology, mathematics and statistics, and most importantly urban morphology. But the real-life application of the knowledge acquired is limited. The pattern of urbanization and the main trend of building our cities remained primarily unchanged.

This paper will focus on different types of researches carried out so far in this Urban Physics domain, and their findings. This state of the art review will also provide a scope for the present authors to identify application potential of different researches in real life scenario. This can bring out scope for further research extensions on the basis of gaps found in research findings.

INTRODUCTION

The planning and designing of urban areas has taken a radical paradigm shift in the last few decades in the developed nations regarding the environmental sustainability. The change transcends from the early energy efficient buildings to the present net positive energy, intelligent buildings, which is really a big step towards the mitigation of the problem of climate change issues and global warming. The awareness of the people, encouragement from the government and social motivators played a great role to bring the wind of change.

The 20th century tendency of "design whatever the client wants, mostly on the basis of cost or aesthetics" (Butler, 2008) is an anomaly and hardly ever leaves much impact in our 'ecological age' (Head, 2008). Presently most of the buildings and urban settlements are designed in a much sustainable way remembering their context and subsequent environmental impact. But, climate-responsive design is becoming more and more difficult due to rapidly changing urban climate and the buildings are depending more and more on artificial cooling, mechanical ventilation and artificial lighting even at daytime. This problem becomes more traumatic in the urban areas of developing nations because of their high density and higher insolation which is further deteriorated due to tremendous population pressure, lack of financial support, political ill-will and ignorance of common mass to retrofit the urban growth pattern for a more positive outcome. The deteriorating urban climate casts doubt on the efficiency of traditional Indian design philosophy of open buildings with fuzzy demarcation between the inside and the out.

This rapid urbanization demands sprawl of the city boundaries and densification of the urban tissues as well. The latter frequently results in the erection of tall structures along narrow streets and complete eradication of green spaces. As a result of the altered climatic balance, the air temperature, humidity, air pollutants and concentration of Suspended Particulate Matters (SPM) in air rises, worsening the quality of life in urban areas by the decreased thermal comfort, acute air pollution, frequent urban floods and increased energy consumption.

In order to apprehend all the problems of urban areas, it is essential to look into the physical properties of the various elements of urban climate. Urban physics is the engineering discipline that establishes the interrelationship of the transfer of heat, wind flow, moisture, pollutants, light and sound in urban areas to have a better understanding on urban climate. The aim of the study of urban physics is to provide an outdoor and indoor built environment that is healthy and comfortable taking into account of existing and future economical, ecological and climatic constraints.

Presently most of the researches in urban physics focus on environmental degradation in urban areas taking into account the Urban Heat Island, evapotranspiration, wind driven rain, pollutant dispersion, wind turbulence etc. Techniques like advance measurement of climatic parameters in boundary layer, sophisticated modelling tools based on Computational Fluid Dynamics (CFD) and wind tunnel simulations are combined together to obtain knowledge about heat, moisture and air flow starting from individual building scale to neighbourhood and entire city scale. The study of urban physics is helping the researchers a lot to understand the urban climate and finding out solution for better urban experience.

OVERVIEW OF URBAN PROBLEMS

Urban areas are plagued with various issues like outdoor thermal discomfort, extreme air Pollution, Urban flood, Low water table, loss of natural vegetation etc. these are basically a result of the interaction between some more fundamental inherent and external factors. If these fundamental issues are understood first, it will be easier to formulate some streamlined mitigation strategies in order to make cities a better place for living. Issues related to the design of urban areas like the materials used to cover the surfaces, placement of plazas and courts, alignment of trees and vegetation etc. play a vital role in urban thermal dynamics. Based on the principles of urban physics high performance computers analyze huge data sets collected by the instruments and help to understand various responsible factors and the interrelationship between them. The most important issues and their impact on urban climate are described below stating their causal relationship with other factors.

Transformation of Urban Surface:

The urbanization of the natural landscape through the replacement of vegetation with roads, bridges, houses, and commercial buildings has dramatically altered the temperature profile of cities. In fact, even within a city, different zones have different temperature profiles, dependent on their surroundings, type of surfaces, and characteristics of ground cover. Urban areas are characterized by dry, impervious surfaces, such as conventional roads, roofs, sidewalks, and parking areas. As cities grow, more greenery is vanished, and more surfaces are either paved or covered with buildings. The transformation in ground cover consequences in less shade and evapo-transpiration to keep urban areas cool. Lesser evapo-transpiration from paved and built up areas contributes to the rise of ground and air temperatures. These transformations affect the natural hydrological cycle within the urban area, leading to extreme surface runoff, reduced baseflows and infiltration, greater amounts of non-point source pollution when compared to areas of a more rural nature, and especially forested areas.

The surface transformation brings in consequential changes in urban hydrologic cycle that contributes to greater localized flooding potential, water bodies that harbour more nutrients and other chemicals, resulting in a greater growth of algae and reduced diversity of fish and wildlife, and a general overall decline in the aesthetics of urban water resources.

Formation of Urban Heat Islands:

In most cities, urban air temperatures are generally greater than their corresponding rural counterparts. This occurrence, the urban heat island (UHI), has been known since the turn of this century and has been well documented (T.J. Chandler, 1960), (T.R. Oke, 1987), (T.R. Oke, 1988). The fluxes of heat, moisture, and momentum are significantly altered by the urban landscape and the contrast between the urban and 'undisturbed' climates is further enhanced by the input of anthropogenic heat, moisture, and pollutants into the atmosphere. It has been observed that the heat island intensities can go up to 10^0C in Indian cities (Pune) (Santamouris, 2001). The probable causes of the formation of UHI as suggested by oke (1982) are as follows:

i. Trapped short and long radiation between the buildings.
ii. Reduced Sky View Factor (SVF) resulting in decreased long wave radiative heat loss
iii. Increased heat storage in urban construction materials
iv. Abundant anthropogenic sources of heat and moisture from fuel combustion
v. Reduced evapo-transpiration
vi. Reduced wind speed resulting in reduced convective heat removal

Though UHIs are not always unfavorable for cold climatic regions (Erell et al., 2011), it substantially increases the cooling load in warm climate and causes serious effects on inhabitants regarding the comfort and health issues. The increased urban temperature not only creates acute heat stress, but it also leads to psychological and behavioural changes along with the reduction of human physical and mental performance which leads to lesser productivity (Evans, 1982).

Increased Energy Demand:-Increased energy demand costs the consumers and municipalities more energy related expenses to maintain the desired comfort levels. The heating and cooling load of a building depends on the climate to which the building is exposed. Buildings located in the same area can have entirely dissimilar energy consumption pattern due to altered local microclimates. High ambient temperature increases the cooling load and energy consumption as well. It has been stated that for US cities the peak electricity loads increase by 1.5−2 % for a temperature increase of 1 ◦F (Akbari et al. 1992). A number of studies has been carried out using urban physics to look into the effects of urban heat island on various cities like Athens (Santamouris et al.2001), London (Kolokotroni et al. 2010) (Kolokotroni et al. 2006), Kassel (Schneider & Maas, 2010), Tokyo (Hirano &Ohashi, 2009) etc. All studies indicate a substantial impact of the increased urban temperature on the energy consumption of buildings.

Wind movement:

Wind movement in urban areas is much restricted due to the high building density. It results in low air exchange and lower the potential of air circulation in and around the buildings (Hirano &Ohashi, 2009) (Ghiaus et al. 2010).

Convective heat transfer and evapo-transpiration is also affected by lower wind speed. This reduced heat exchange results in excess heat storage in the urban built environment and raises the temperature of urban microclimate which again increases the cooling demand of indoor spaces. As a result of the entrapped solar radiation, the building skin temperature is always higher than the ambient air temperature (Allegrini et al. 2011).

Air Pollution: -

Generation of more electricity by power plants leads to higher emissions of sulfur dioxide, nitrous oxide, carbon monoxide, and suspended particulate matters, along with carbon dioxide. Development of urban heat islands often escalates the formation of photochemical smog, as ozone precursors like nitrous oxides (NOx) and volatile organic compounds (VOCs) reacts photochemically to form ground level ozone.

As the intrinsic characteristics of the natural landcover is transformed in the urbanization process, the energy exchange which takes place within the boundary layer are highly affected. Transformation of the natural ground cover influences the local (microscale), mesoscale, and the macroscale climate and disrupts the natural route of energy flow through the land, atmospheric and water cycles.

Planning Issues:

A number of planning related issues are responsible for continuous degradation of urban climate. In most of the cities, urban growth happens in a haphazard way without proper planning. Though the urban development guidelines tell some sort of indirect guidelines, the planners and urban designers often neglect the issues. In most of the cases they only visualize the space but fail to apprehend impact of the proposed development after their construction on urban climate. The climatic data that are taken into account, mostly collected by the weather stations which are placed at a much higher height. The actual ground level climatic parameter and the impact of local anthropogenic factors like mutual shading and reflected heat from surroundings, very often remain unnoticed.

Absence of mandatory energy efficiency codes and the resulting energy wastage from buildings also play a vital role in deterioration of urban climate. Building energy efficiency policies and programs are mostly in an active design stage with limited implementation to date. Decision-making authority at the national level is spread between several agencies and program design and implementation responsibilities are spread across a large number of state and municipal agencies, resulting in a diversity of implementation regimes and little coordination. This micro level reduction in energy use can cumulatively make a great impact on improvement of urban climate.

The role of urban physics in better appreciation of the problems of urban climate is indisputable. A lot of researchers are working in this field presently in order to solve the problems generated by rapid urbanization in various parts in the world. For an in depth appraisal of urban climate in urban neighbourhoods and street canyons, the combined effect of solar radiation, wind flow and evapotranspiration is studied. Modelling and simulation of various cases are performed using computational fluid dynamics (CFD), Radiation simulation and whole building simulation tools. Wind tunnel simulations are often carried out to validate the CFD simulation. By varying the various parameters of the model (like building density, green plot ratio etc.) the impact on microclimatic variables like outdoor temperature, wind speed etc. are observed and optimum solution can be proposed.

APPLICATION OF URBAN PHYSICS

Urban physics not only helps a lot to identify the problems of urban areas but also has the capability to suggest the optimum solutions of the problems.

A substantial amount research has been done to reduce the detrimental impact of urban climate change which suggests various measures like the use of evaporative cooling from ground level (Kruger and Pearlmutter, 2008) and rooftop water bodies (Runsheng et al.,2003; Tiwari et al.,1982) or make use of evapo-transpiration from wetted ground. Alternatively the design of the buildings with lesser exposed flat surfaces to control the direct solar access and aerodynamic design of the building can facilitate wind movement in and around it to improve the urban microclimate.

Considering the context of cities where the high humidity level, acute shortage of land is a burning issue, the solutions mentioned above are not feasible. As of today, most of the buildings in cities of the developing nations are built without any professional input and custom made passive design solution for every single building is a farfetched dream. Rather the protection of existing landscape by facilitating urban forestry, increasing the surface albedo by applying reflective materials especially on horizontal surface and plantation of shade providing trees along the road and around the buildings seem to be a more implementable solution. Among all known strategies of urban climate mitigation, a few, befitting the present context are discussed below.

Implementation of Urban Green Infrastructure:

‘Green infrastructure’ (GI) is a term used to delineate a network of greenways, parks, and untransformed open spaces, which are basic modules of urban environments (Benedict and McMahon 2006). (Kambites and Owen 2006, 484) specified that green infrastructure denotes “connected networks of multifunctional, predominately unbuilt, space that supports both ecological and social activities and processes”. These systems provide assorted psychological, economic, social, and environmental benefits to urban individuals and communities (Forest Research 2010); (Manning 2011), and are essential in city planning and design (Walmsley 2006). Green infrastructure focuses on strategic planning to identify and protect wetlands, forests, and other natural components that deliver crucial ecosystem services.

GI includes the community “greening,” in which trees and plants are used tactically for stormwater management and other functions in urban areas. Urban greening ranges from planting streetside trees, installation of high albedo surfaces and rain gardens to installation of green roofs and planters on high-rise building balconies. Urban greening is very important to mitigate the extremities of urban climate and it provides several types of additional benefits to the urban community including richer biodiversity, pleasant visual experience, reduction of stormwater runoff and more groundwater recharge.

Green roofs:

Installetion of green roof can passively cool the air above it and the indoor space below, (Köhler, 2004) (Teemusk and Mander, 2009) reduces the stormwater runoff, tackles air pollution by absorbing the pollutants and Suspended Particulate Matters (SPMs) and so on. The higher reflectivity of the foliage of the trees compared to common roof materials results in lesser absorption of radiated heat. Their higher emissivity also facilitate long-wave radiation and so radiant cooling (Gaffin et al., 2005) (Gaffin et al., 2006).Green-roof shades the roof slab by obstructing solar radiation. It offers thermal insulation to obstruct heat absorbed at the upper surface toward the roof slab (Lazzarin et al., 2005) (Getter et al., 2011).

Use of High Albedo Surface:

Roofs and pavements constitute around 60% of urban surfaces in many urban areas (Akbari et al., 2003) (Rose et al., 2003) (Akbari and Rose 2001). It is also demonstrated in many studies that an increase of roof reflectivity from 10-20% to 60% can generate energy savings excess of 20% in many cities. Increase of albedo of roofs and pavements can improve the air quality and reduce the summertime temperature in urban areas (Taha 2001) (Taha et al. 2000) (Rosenfeld et al. 1998). Due to the increased reflectance of urban surfaces some amount of incoming solar radiation can be reflected back and can counter global warming also (Kaarsberg and Akbari, 2006).but this strategy can only work in the case where the solar radiation is reflected back to the space and not entrapped between the building due to multiple reflections.

Promotion of Urban Forestry:

Urban forests can ameliorate the urban climate by restricting direct solar radiation, facilitating wind movement, removing SPMs and pollutants by the means of bioretention. It can lower the overall temperature of the surrounding by at least 2 ^{0}C-8 ^{0}C by the means of increased evapo-transpiration (Oke, T.R., 1987), (Taha et al, 1989). The shade provided by urban trees can be the single most important parameter to increase the overall thermal comfort as the direct solar radiation has the maximum impact on the surface energy balance (Taylor and Guthrie, 2008). The most favourable design solution is a layout where the buildings and trees together mutually shade the open spaces and roads (Emmanuel and Johansson, 2006), (Erell, 2008).

Policy Level Mitigation Strategies

Planning policies, guidelines and development control regulations actually determines the urban geometry. Though there is a subtle linkage between policy framing and urban physics, appropriate planning and development control regulations can facilitate the solutions that came out from simulation of various city models. At the same time, proper implementation of those guidelines should also be ensured.

Urban geometry has a strong influence on urban climate and the comfort level. It has been observed that a compact urban form with very deep street canyons and lower sky view factor (SVF) can create lower temperature (Cool Island) providing shade to the pedestrians in hot dry climate (Pearlmutter et.al. 1999) (Givoni,1998). On the contrary, dispersed urban forms create an extremely uncomfortable environment in the summer. So urban physics can indirectly guide the framing of building bylaws of a city depending upon its climate.

From the above discussion it is understood that urban physics not only gives the researchers an in depth knowledge of the problems regarding urban climate but also helps to find out the solutions for the same. The advancements in this field of research will certainly help to build better cities with better living experience.

INTEGRATION IN URBAN DESIGN

The comfort level of cities are highly compromised due to their high pollution level, formation of UHI, and reduced thermal comfort. Framing the Urban design guidelines according to the findings of the researches following the principles of urban physics can can lead to the optimum urban setup. Taking the case of a city in warm humid climate, it can be observed that the stagnant air mass inside the city helps to form UHI, rises the humidity level and concentrating the pollutants and SPMs which altogether deteriorates the urban experience. But improvement of wind movement inside the city can substantially improve the scenario. Strategic placement of the tall buildings in the urban fabric can extensively improve the wind flow in the city. But placing the tall building in a dense pattern restricting the wind penetration inside the city is not recommend in this particular case. So setting the building bylaws in favour of higher FAR and lower ground coverage in some strategic plots and designing the urban area in accordance with it can be very helpful to improve the outdoor comfort and reduce the outdoor temperature which results in substantial energy savings.

But this same urban setup can become incompatible in the case of cold and windy cities. The opposite approach, i.e. clustering of tall building in the path of prevailing wind restricting the wind flow can reduce the pedestrian level wind movement to a comfortable level and prevent the conduction heat loss from building skin. Appropriate and contextual urban design guidelines understanding the principle of urban physics can thus improve the urban experience and reduce the energy demand as well.

In the case of a number of tropical and subtropical coastal cities, moist air comes from the seaside.

The hot urban area underneath heats up the moist air and it rapidly goes up followed by sudden cooling and formation of dense clouds. But the wind drives the clouds on the other side and heavy rainfall happens in the opposite side of the city of the direction of that incoming moist air from the sea. This unequal heavy sudden rainfall results in unprecedented high intensity urban flooding in those cities. Cities like Kolkata, Mumbai, Puri, Kochi, Surat are some common example of this incident in India. The urban poor or those who live in slums are mainly affected by urban flood especially in cities like Kolkata and Mumbai where the slums are located in low lying ecologically fragile areas

There is a need to access the probability and extents of occurrences of these incidents and design the urban area accordingly facilitating prolonged runoff time using urban green infrastructure, more permeable surfaces, more urban greenery and improving the efficiency of stormwater drainage. This can reduce the chances of vulnerability of the services and the inhabitants as well. Therefore many of the urban design principles for sustainable and climate resilient development of the cities require the inputs from urban physics for betterment of their performance.

THE INDIAN SCENARIO

Since the economic reforms started in 1991, Indian economy is growing at a fast pace. Due to migration from rural to urban areas, India's urban population is expected to reach 472 million in 2020 and 611 million in 2030 compared to 325 million in 2005 reaching a share of 41% of the total population resulting in urban sprawl and densification (MGI 2010). To accommodate the migrating population, the construction industry is also growing at a fast rate contributing an average 6.5% of GDP (JLLM 2007).

Indian cities grow in a ridiculous way by inclusion of urban fringes in the municipal areas. When a city starts to grow, the land price of its surrounding village areas go up and development of the rural areas start according to the rules and regulation of the rural areas having narrow roads and lack of public amenities. It does not support any future improvement due to high built up areas and virtually no open space. When these peri-urban settlements are included in the urban municipal areas, the problem increases many fold due to the further increased population pressure. These areas may be retrofitted with some basic services and amenities, but the situation remains the same. These densely packed buildings (mostly without mandatory open spaces) creates a havoc impact on the urban climate because of complete extinction of greenery, extensive hard paved surfaces and the least space for wind movement.

In most of the cases, Indian cities only have municipal building byelaws which only deals with one individual building but they do not have any comprehensive strategy or guidelines for developing the public spaces considering the outdoor comfort and convenience in the urban realm. The existing building bylaws are often disobeyed which creates problems in wind movement, water percolation etc. Even the buildings in the National Capital Territory of New Delhi, comply with building codes less than 35% of the time (WB & IFC, 2009). Considering the unsustainable growth of the urban areas in India, a number of policies are introduced to facilitate the energy efficiency and green building as a control and regulatory measures including appliance ratings and certifications. But almost all the measures deal with an individual building. No visionary guideline has not been developed considering a neighbourhood level or city level.

Though in March 2011, BEE asked for the compulsory enactment of ECBC at the local level in eight states starting in 2012: Delhi, Maharashtra, Uttar Pradesh, Haryana, Tamil Nadu, Andhra Pradesh, Karnataka, and West Bengal (PTI, 2011).

The data on existing building stock in India are incomplete and estimates about the total floor space, number of units and typology of building (commercial, residential or industrial) vary considerably. With this limitation, the following facts and figures should be viewed as approximation. The total building stock in India has experienced an annual average growth of 6% between 1990 and 2005 resulting the doubling of floor space from 4 to 8 billion m2. From 2005 to 2030, the average growth is expected to be 6.6% resulting 22 billion m2 in 2020 and 41 billion m2 in 2030. The growth pattern represents that almost 70% of the buildings that will exist in 2030 have not been built yet which actually leaves a window of opportunity to make substantial improvement of urban climate. (The World Bank, 2010). There is an urgent need to develop an urban development guidelines with a strong emphasis on the mitigation strategies of climatological and environmental impacts of urban development.

It is an agreed upon fact that Indian cities need much more attention for their extreme and as well as diverse character and as most of the future cities are yet to be built, there is a great scope of implementation of urban physics in designing Indian cities. Though a lot of researches has been carried out but the real life implementation of urban physics in urban design is yet to gain its momentum in the subcontinent.

CONCLUSION

The amelioration strategies discussed above came only through the research of urban physics and gives a direction to improve the experience of urban areas and explore new areas for improvement. It is evident that most cities suffer due to their air quality (pollution), thermophysical quality (thermal comfort) and water related issues (urban flood, low water table, etc.) (Campbell-Lendrum & Corvalan, 2007). In most of the case they are linked with one another in the urban ecosystem. So, the architects, urban designers and planners need to use urban physics to understand their interrelation for a practically implementable, streamlined and unified approach to start the development of mitigation strategies to deal with the unintended urban climate change.

The development route of world civilization till date has made it very clear that the population growth and urbanization will continue at a very rapid pace. Development of a number of new cities and expansion of the existing ones is a necessity. Therefore, there is an urgent need to develop new sets of urban design guidelines that comply with the research outcomes of urban physics to ensure that the upcoming buildings and the corresponding urban areas go along with today’s most efficient, climate resilient design and planning strategies.

Though the subject, urban physics, comes with a world of opportunities, it has some downside too. The correlation between various factors of urban climate, huge data sets and highly complex mathematical calculation demands profound knowledge of the subject and substantial amount of computational resource to run the simulations. Supply of resources and availability of experienced professionals and a streamlined networking among all the stakeholders is necessary for its success.

Though urban physics mainly deals with a group of buildings, neighbourhoods, urban canyons etc. special emphasis has to be given on the design of individual buildings also as they cumulatively contribute to the overall urban experience. Considering the common trend of having very less building designs with professional inputs in most of the urban areas, the situation is going to deteriorate much more in the foreseeable future. It is very important to get the urban fabric right so that every single building have the capability to extract the maximum environmental potential with or without professional interventions echoing the ethos of traditional Indian design with a fuzzy demarcation of indoor and outdoor.

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Assessment of Solar Access in different urban space configurations in two southern latitude cities with mild climates.

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ABSTRACT

One of the characteristics of passive low energy architecture is the dependence of its facades on solar access. However this aspect is little considered by law or in the practice of real estate development. On the one hand, urban space configurations such as streets are defined in planning guidance by law to safeguard the common good, but on the other, real estate activity puts pressures on land and creates large buildings occupying maximum plot ratio. This is particularly the case in developing societies and emerging economies. One of the direct effects of this process is solar obstructions on the urban space, i.e. facades, ground and sky. This means that indirect passive low energy opportunities which affect the possibility to capture energy for passive or active systems are lost with new high-rise developments creating unequitable environments. Therefore, the design of urban space which considers solar access to facades becomes an important issue as a means to avoid these problems.

This paper seeks to explore designs which permit solar access within the context of urban practice which permits large building volumes. Here different street configurations are examined to evaluate to what extend it is possible to balance solar access and plot ratio criteria in planning guidelines. This investigation examines four urban space configurations from lower to higher density to discover the range in which both criteria present compatibility. Two cities located at two different latitudes are compared to assess solar irradiation availability on the surfaces of facades, the ground, the roof and the urban space. A simulation was carried out on winter and summer solstice with 2 urban orientations: east-west and north-south axis. Results show an inflexion point in the curve of irradiance according to geometrical profile. These findings help to orientate planning guidelines in the consideration of passive low energy architecture to promote a more sustainable habitat in developing societies.

INTRODUCTION

Contemporary cities in the context of emerging economies tend to experience growth both outwards on the periphery and upwards in high density central areas with planning guidelines trying to control development. Whether in horizontal or vertical expansion the built environment is shaped by economic forces that try to maximize plot ratio and building floor-space. One of the effects of these developments are towering high rise blocks which shadowed streets and surroundings impacting on solar access for urban spaces, facades and buildings in cities as shown in **Figure 1.**

On the other hand the Chilean urban regulations try to order urban morphology and spatial arrangements through morphological constraints such as; distance to boundary (“rasante”), plot ratio,

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built floor coefficient, shadows above plot, amongst others. These parameters are useful to shape urban form for individual buildings on a single plot but not necessarily achieve a coherent morphology at city-block level. The emphasis on individual buildings in the urban regulations results in the poor design of three dimensional spatial surroundings. Regulations determine parameters which are concerned with architectural built form which theoretically allow the access of sunlight but in practice shadows are really only taken into account as a spatial limit to the height of buildings rather than any concern for energy use in passive and low energy architecture.

(a)

(b)

Figure 1 (a) dark street from shadowing and high rise buildings and (b) panoramic view of Santiago city to the East side.

Nonetheless, from a solar perspective planning guidance should consider the shading effects of buildings on their surroundings because this has an impact on the opportunity of daylighting and passive or active heating. Equity is put at risk when solar obstructions from high buildings fall on a neighborhood regardless of a minimum solar access to sunlight or daylight. The question is how to protect solar resources for every neighbour within cities? This is particularly important in cities which belong to the world's 'sun belt' which have extremely high irradiance and opportunities to benefit from this resource, such as in the case of Chilean cities. As an example the southern German city of Freiburg is known as the "solar city" with enormous solar PV cells and solar thermal investment integrated to the architecture. It is located at latitude 45°N which is considerably further north and therefore receives less radiation, than Chile's southerly cities, for example Puerto Montt at latitude 41°S. Therefore there is enough radiation to justify exploring solar options in Chilean cities not only in the north but also in the southern territory. Therefore it is argued that urban planning instruments should recognise the potential of solar access throughout the whole of Chile whilst considering the different contexts which may create different opportunities.

International institutions have stated that traditional approaches to urban planning have failed to promote equitable, efficient and sustainable human settlements for addressing twenty first century cities in developing countries (UNHS, 2009). However, there are many authors studying specific issue such as solar access on buildings and cities to deal with energy and spatial conditions to save urban morphology. (Capeluto, 2001; Košir et al., 2014; Lau et al.., 2011; Benoit, 2012)

The general objective of this paper is to explore urban design which allows solar access within the context of urban development which permits large building volumes regardless of energy capture on urban surroundings. Cross-section of streets with different configurations (width/height ratio) are examined to evaluate to what extend it is possible to balance solar access and plot ratio criteria in urban planning guidelines.

Amado et al (2013) state that solar urban planning is a complex process that requires interplay between many factors related to urban form and solar energy inputs. The authors use a parametric approach to quantify solar energy from photovoltaic systems in the urban context (Amado, 2013). They argue that solar power plays a strategic role in improving the energy efficiency of cities because it could be used to generate clean energy for consumption and perhaps match demand. Both these functions are key indicators to understand the balance of energy performance in city neighbourhoods.

In the city of Oeiras, Portugal, an algorithm has been developed to estimate the annual energy production for PV systems. This has been applied to specific urban configurations such as the cellular unit called the "warped parallel". Three factors were used to classify the city into different cellular units;

year/period of construction, population density and representative morphological patterns. The element of ‘roof surface’ was the mean element used to study the PV solar electricity potential. Here they compared energy demand and solar supply in the urban system with existing typologies of building block and street pattern. This appears to be a useful tool for consolidated urban areas but the question arises as how to plan the future urban configuration with a huge diverse morphological pattern.

With this in mind, we propose that a simple cross section analysis might support planning guidance in the future to control height of buildings considering both interests of maximizing urban densities and providing solar access to neighbouring buildings.

Current controls and guidance on urban morphology include “Site Layout Planning” of the Building Research Establishment (BRE) of Great Britain which has been in use since 1991 (Littlefair, 2011). This document advocates access to skylight and sunlight because these contribute to building energy efficiency. Daylight will reduce the need for electric light, while solar gain can help meet heating requirements in winter.

Additionally ‘Development Advice Notes’ exist at local municipal level in the UK to help applicants in submitting their planning applications. For example, Stirling Council in Scotland has produced a document to give general advice on daylight, sunlight and privacy on new development or extensions. Here they look for a balance between expectations of the homeowners and the effect of that development on the locality. The discretion of the Council is relevant to give permission for any changes in the built environment and daylight in this case is a guiding principle rather than sunlight.

These guidelines are set out to minimize the overshadowing of neighbouring properties for the majority of the day where the design should confine shadow projection to the applicant´s own land. The factors considered in the design are height, distance to boundary, size of plot, orientation and topography on plan. A “degree approach” refers to the angle allows daylight at the “centre of the closest ground floor habitable room window of neighbouring properties” (Stirling Council, 2002).

Finally, urban canyon has been analyzed as an element used to characterize the street in relation to the climate, meteorology and urban design by many authors (Oke, 1986; Mills, 1993; Pearlmutter et al., 1999; Venegas y Maceo, 2012; Andreou, 2014; Botillo et al., 2014). In this paper urban canyon was chosen to create a conceptual model for studying available solar direct radiation.

RESEARCH METHODOLOGY

In order to analyse effects of different urban configurations on solar access a parametric approach was applied. To achieve this objective a digital model was constructed considering a typical cross section of a street found in central areas of the city as shown in **Figure 2**. Two parameters were tested: irradiation (Wh/m2) and ratio height/width (1:1, 1:3, 1:5, and 1:7) where the heights of buildings were changed while maintaining a constant street width as shown in **Figure 3** for each city and **Table 1.** This model was chosen because it represents urban spatial configuration that involves a topological relationship between facades and urban space. This means that analysis is not only of single buildings, as is traditional, but of two buildings which interact with the urban spaces and hence the human habitat.

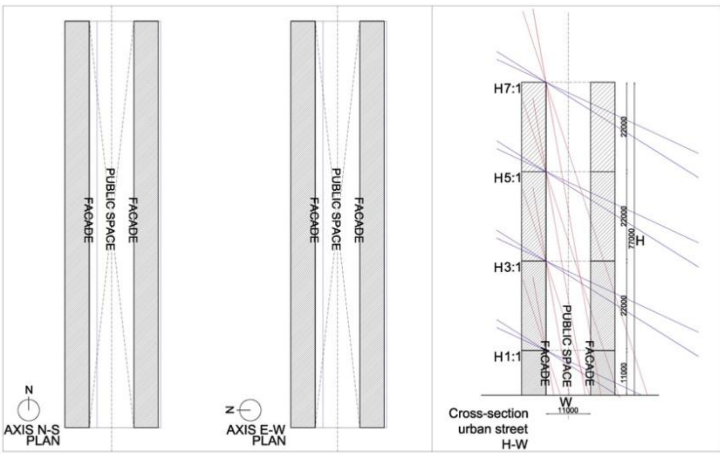
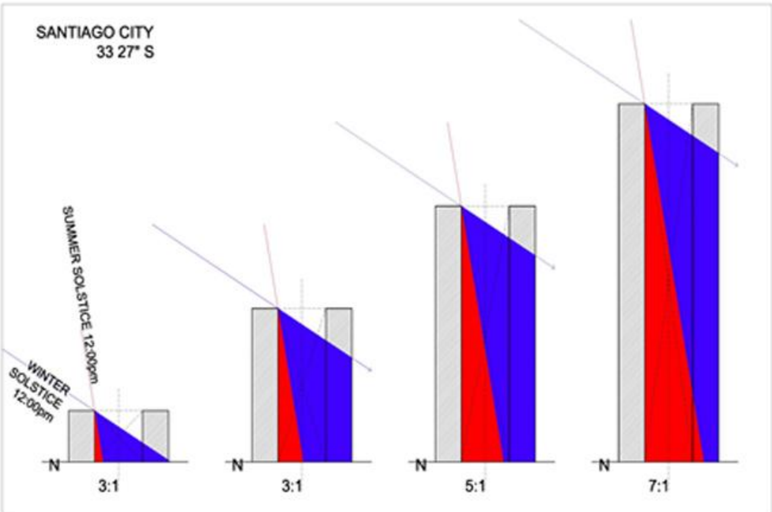


Figure 2 A cross section model of urban street canyon

Table 1. Parameters of the model based on Cross section of streets

Width of street between official line	ID	Height of building (N° of floor)	Proportion of urban space (W/H)	Factor of constructibility (ratio: floor surface / site surface)
11	A	4	1:1	0.99
11	B	12	3:1	1.98
11	C	20	5:1	3.96
11	D	28	7:1	7.92

Two cities which have witnessed rapid growth and urbanization located in different latitudes and climates were selected to examine incident radiation on facades and urban space. To achieve this, the same cross section model was analyzed to compare how spatial configuration works in different climates. Four configurations were chosen according to proportion of urban space and two street axis orientations: North-South and East-West. The criterion for urban spatial configuration was a growing density from a lower to a higher extent to discover the range in which both objectives present compatibility: solar access and density. The questions were; To what extend it is possible to raise the height of buildings and have available solar radiation? and, How to balance both objectives to get a maximum solar energy on facades and a maximum high rise buildings?



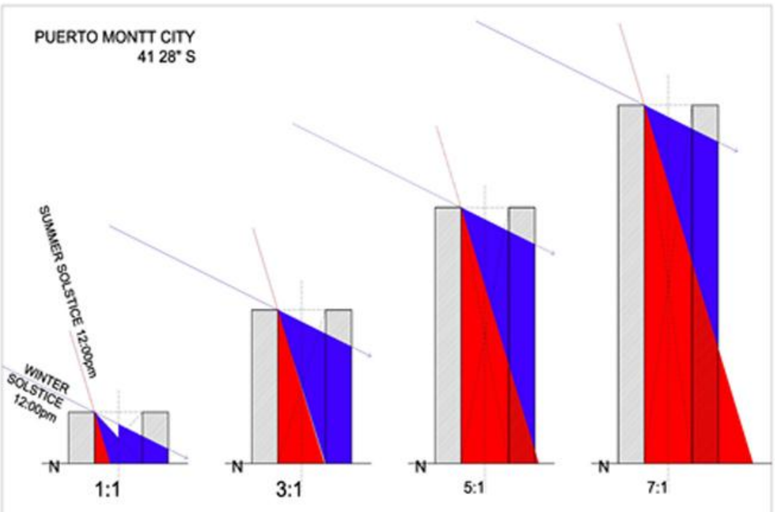


Figure 3 Urban spatial configuration proposed for analyses pointing out solstice angle.

Table 2. Simulated value of solar incidence on facades and urban space in two cities: Puerto Montt and Santiago as a daily average on solstices: 21Jun and 21 Dic.

FACADES (wall)

	PUERTO MONTT 41° 28' S					
PROPORTION	EAST WEST AXI	Average energy (kWh/m2)		NORTH AXI	Average energy (kWh/m2)	
H:W		21-Dec N/S	21-Jun N/S		21-Dec E/W	21-Jun E/W
1;1		2,06	1,22		4,14	0,8
3;1		1,79	0,49		2,08	0,48
5;1		1,40	0,34		1,4	0,4
7;1		1,15	0,28		1,08	0,36

URBAN SPACE (Street)

	PUERTO MONTT 41° 28' S					
PROPORTION	NORTH AXI	Average energy (kWh/m2)		EAST WEST AXI	Average energy (kWh/m2)	
H:W		21-Dec N/S	21-Jun N/S		21-Dec E/W	21-Jun E/W
1;1		5,38	0,02		3,1	0,48
3;1		2,45	0,02		1,31	0,33
5;1		1,72	0,02		0,90	0,32
7;1		1,65	0,02		0,75	0,32

FACADES (wall)

	SANTIAGO 33° 26' S					
PROPORTION	EAST WEST AXI	Average energy (kWh/m2)		NORTH AXI	Average energy (kWh/m2)	
H:W		21-Dec N-S	21-Jun N-S		21-Dec E-O	21-Jun E-O
1;1		1,24	2,2		4,16	1,36
3;1		0,86	0,87		2,12	0,78
5;1		0,76	0,6		1,42	0,62
7;1		0,70	0,49		1,08	0,56

URBAN SPACE (Street)

	SANTIAGO 33° 26' S					
PROPORTION	NORTH AXI	Average energy (kWh/m2)		EAST WEST AXI	Average energy (kWh/m2)	
H:W		21-Dec N-S	21-Jun N-S		21-Dec E-O	21-Jun E-O
1;1		6,30	0,05		3,34	0,92
3;1		4,61	0,05		1,37	0,56
5;1		3,29	0,05		0,90	0,51
7;1		2,53	0,05		0,70	0,51

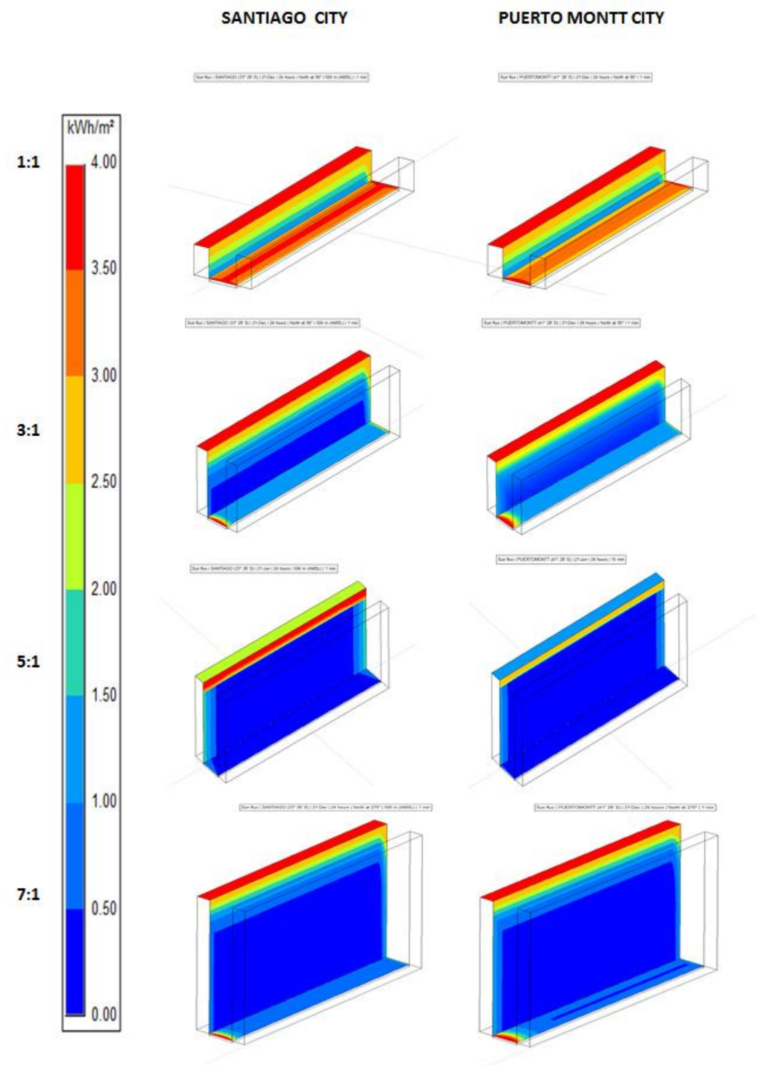


Figure 4 Simulation of solar radiation on cross-section of urban street

RESULTS AND CONCLUSIONS

First of all energy simulation has carried out by using Heliodon ™ software to measure irradiation on facades and urban space assembled on two axis: North-South (N-S) and East-West (E-W). Total direct radiation incidence on both facades in front of the urban canyon was calculated which was divided by available surface on building in square meters to give the average energy. Masking has been considered in calculations during one whole day: summer and winter solstice, as shown in **Figure 4**. The same method was used for ground as horizontal data and all those values were registered in **Table 2**. In **Figure 5** the chart shows curves energy performance according to proportion of street expressed through ratio H/W (height/width) such as 1:1, 3:1, 5:1, and 7:1.

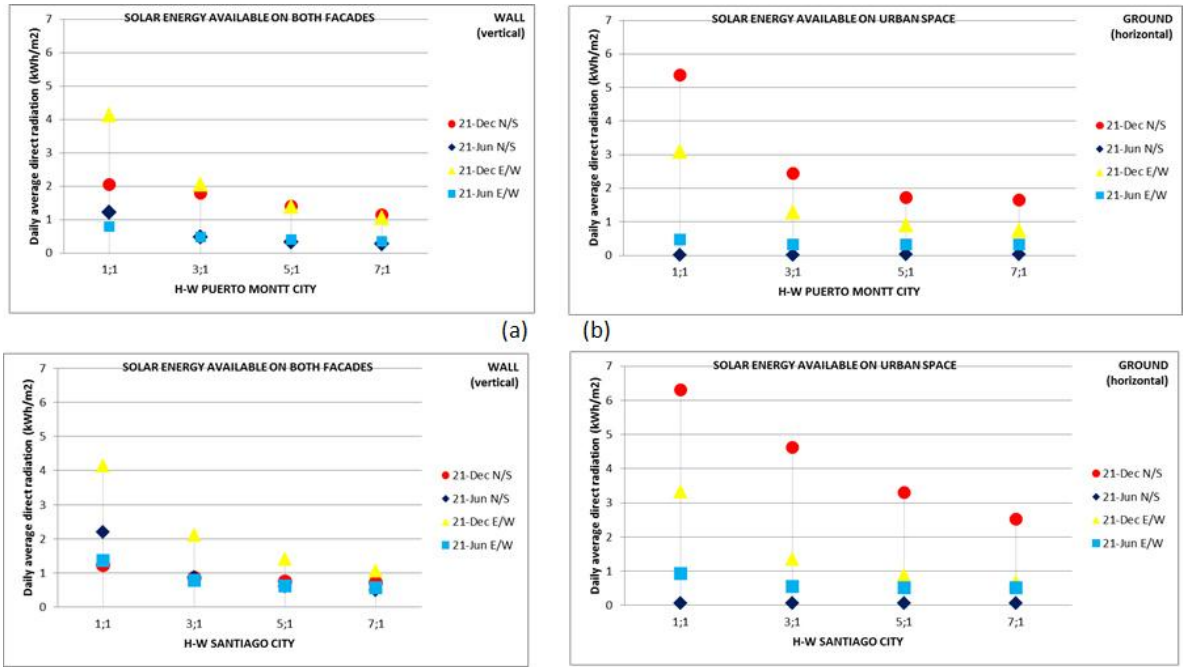


Figure 5. Solar irradiation available on facades and urban space considering mask from buildings in front during solstice and growing density.

Results from **Figure 5** show an inflexion point of facades curve at 3:1 proportion of the canyon in both cities of Santiago and Puerto Montt. After that radiation curves continue to slowly descend as density increases (higher buildings). Energy available on facades also changes according to the orientation of street axis and climate. If direct radiation is compared between the two cities the maximum values are observed in East-West facades during summer solstice (21 Dec). Similar values are observed in East-West facades during winter solstice as well (21 Jun). However values (kWh/m2) in North-South facades present differences in both cities whether summer or winter solstice. For instance, Puerto Montt registers almost twice the amount of solar energy values in summer and same situation as in Santiago but in winter. A conclusion might be that North-South facades within an urban canyon are relevant to assembled grid on urban design project and hence planning guidance.

In **Figure 5** (a) it is also observed that the proportion of urban canyon becomes another relevant parameter for similar values. Given 3:1 in winter solstice in Santiago city is of a similar energy value to 1:1 in winter solstice in Puerto Montt city. So a conclusion for planning guidance is high rise buildings should be allowed in latitude closer to the equator (Santiago) rather than far from them (Puerto Montt). If the width of street is enlarged it would capture solar energy. A balance between solar gains in front urban facades is possible when a proportional magnitude of streets is managed by town planners at local government level.

Following this conclusion it is relevant to find out that some different orientations and different solstices in the same city of Santiago deliver equivalent solar direct radiation on facades. Values obtained from East West facades in winter are equivalent to North-South facades in summer solstice. By contrast, in the city of Puerto Montt different orientation in the same climate delivers equivalent values. Therefore a conclusion is that each city has equivalent values combining orientation of the street and weather (solstice). These findings might be useful for urban planning guidance which wants to consider solar energy as input for the architectural envelope in the urban context rather limited to the isolated conditions of laboratory simulation.

In **Figure 5** (b) solar irradiation on urban spaces presents a higher value in Santiago than in Puerto Montt as expected, at the summer solstice there is a 1kWh/m2 difference in value. However values tend to be similar when approaching winter with a similar curve at the solstice of June 21th. An inflexion point occurred at the 3:1 proportion of urban space in both cities. The north-south axis presents more dispersion in respect to the east-west. The proportion of 7:1 in Santiago is equivalent to 3:1 in Puerto Montt therefore high-rise building might be managed to have a similar potential of solar access.

Finally a comparison of irradiation performance on facades and ground surface regarding the proportion of urban space has been analysed with simulation modeling. Solar energy performance changes significantly if facades or ground surfaces are analyzed considering masking. A balance between both initial objectives, highlighted at the beginning as solar access and urban density, is possible to achieve when analysing values from simulation as this paper demonstrated. Decision making might be taken by local planners through physical parameters such as proportion of street canyon. It is interesting to discover that similar solar energy values can be obtained depending on the height of buildings in two cities with different latitudes. More specifically, it is possible to manage the proportion of urban space through finding out the relationship between ground width and building height. These parameters would help urban design and planning guidance at local government.

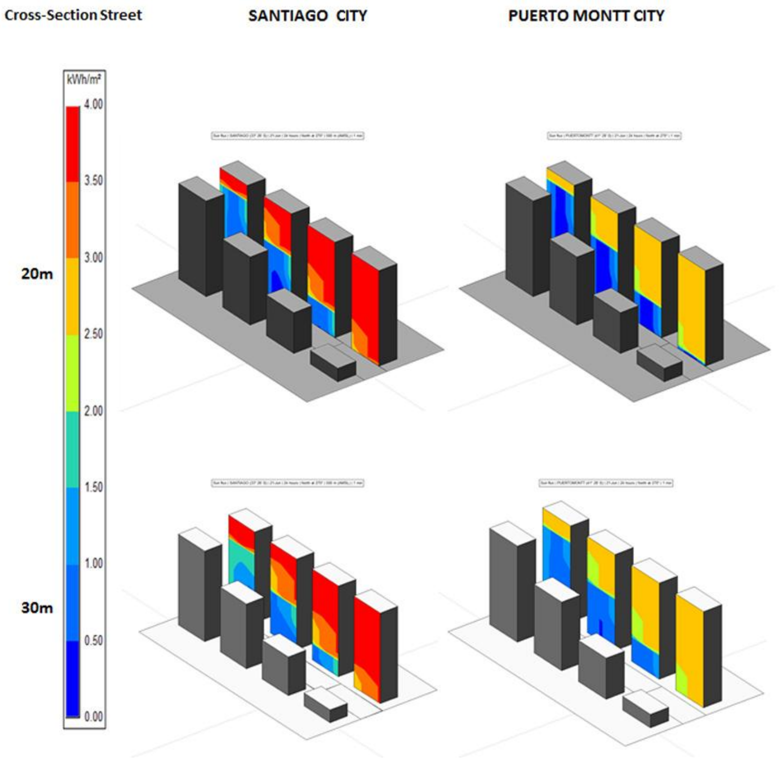


Figure 6 New arrangement buildings are placed on land plots varying the width of the street.

To evaluate more complex changes in building geometry the model is rebuilt with different heights for both cities during the day of least favorable solar radiation, the Winter solstice (June 21). In this new arrangement buildings of different heights are placed on land plots as an alternative to the continuous urban canyon and this time varying the width of the street. **Figure 6** shows a simulation of solar flux intensity (kWh/m2) falling on the façade of a building on a street of 20m (top) and 30m (bottom). An inverse relationship was discovered; as the width of the street becomes greater the direct solar radiation available on the north façade facing a solar obstruction is slightly lower for Santiago. However the model for Puerto Montt shows a direct relationship; as the width of the street increases the direct solar radiation available on the north façade increases. Since Puerto Montt is at a lower latitude than Santiago it could be inferred that in high latitude cities, increasing the width of the street optimizes solar energy in northern facades, but in cities of a lower latitude this spatial parameter works the opposite way.

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Session PB : Vernacular Architecture

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10. Compassion - Knowledge Consortium of Gujarat

An Analysis of the Potentialities of Portuguese Vernacular Architecture to Improve Energy Efficiency

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ABSTRACT

Vernacular architecture is characterised by a type of formal expression that has been developed in response to a number of factors – climatic, lithologic, cultural and economic – characterising the local area or region. In its various forms, a range of techniques has been employed in different regions to mitigate the effects of climate. Despite the fact that Portugal is a small country, it has a territory full of contrasts, which gave origin to many different architectural manifestations. The approaches adopted in the design and construction of vernacular buildings have the potential for further development and could be adapted in response to contemporary needs. In the future, a blend of tradition and modernity should be aimed at in order to develop a new form of aesthetics and functional construction. Portuguese vernacular architecture is associated with a fund of valuable knowledge that should be studied and aligned with the principles of sustainability. In this paper, is presented the climatic contrast between the northern and southern parts of Portugal and the relation with the purpose of different passive solar techniques used in vernacular architecture to provide comfort. The focus is on the effectiveness of passive cooling techniques (e.g. high thermal inertia, the use of light colours and patios), and the findings of a case study in which the thermal performance during the summer of a vernacular residential building located in the south of Portugal are presented. In the context of the current global drive for clean energy and sustainable buildings, much can be learned from a review of past experience in order to provide an understanding of such forms of construction, which are an intrinsic feature of specific places and have evolved over time in the face of a lack of resources.

INTRODUCTION

Nowadays, sustainability and energy efficiency are inevitable discussion topics for building industry. This industry is one of the largest raw materials and energy-consuming sectors of the economy and responsible for almost a third of all carbon emissions (Ürge-Vorsatz, Danny Harvey, Mirasgedis, & Levine, 2007). In order to address this problem various bodies have set medium and long-term targets for improving efficiency in construction, such the European Union that has outlined a path of 70% of reuse/recycling/recovery of construction and demolition waste by 2020 (European Comission, 2012) and an 80-95% reduction in CO_2 emissions by 2050 (EEA, 2012).

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In order to achieve the above-mentioned objectives, there is an urgent need to rethink the ways of building. In a era of globalization that led to the homogenization of the different ways to build, according to some authors we should reflect on past experience, since traditional buildings are an example of a more sustainable construction and so they could have an important role to play in the future of construction (Foruzanmehr & Vellinga, 2011; Oliver, 2006). Intrinsically bound up with the local conditions, vernacular architecture could contribute towards reducing waste and energy consumption through the use of passive solar design, traditional techniques and local materials, which were developed in accordance with a specific territory and climate (Fernandes, Mateus, & Bragança, 2013; Kimura, 1994; Singh, Mahapatra, & Atreya, 2011).

This paper is focused on energy efficiency (other sustainability categories are not discussed), since this issue is particularly relevant in the contribution of vernacular architecture towards sustainable building. This is because vernacular buildings gave prime importance to passive climate control for ensuring indoor conditions of comfort. Additionally, the strategies used to mitigate the effects of climate are usually low-tech and not very dependent on non-renewable energy, while they do not require special technical equipment, which makes them suitable for contemporary construction, especially passive building design. In this sense it is important to highlight that a passive houses provide the lowest contribution in terms of such equipment as far as LCA results are concerned, mainly due to the fact that there is little need for conventional ventilation and air-conditioning equipment (HVAC) (Passer, Kreiner, & Maydl, 2012).

Although "Energy" is just one of the sustainability categories, several comparative studies (Forsberg & von Malmborg, 2004; Haapio & Viitaniemi, 2008) about Building Sustainability Assessment (BSA) tools have shown that energy efficiency is a relevant aspect of the overall sustainability of a building. For example, according to the Portuguese assessment and rating system (SBTool^{PT}), the "Energy Efficiency" category has the highest weighting (32%) in the assessment of environmental performance and the third highest weighting in the assessment of the global sustainability of a building (Mateus & Bragança, 2011). Energy consumption is also a key issue in terms of the environmental life-cycle impacts of buildings, mainly during the operation stage, and is related to the provision of healthy and comfortable conditions for occupants (Passer et al., 2012)

Nevertheless, some studies have been carried on the passive strategies used in Portuguese vernacular architecture, the state of the art is that there are no results available from *in situ* measurements that can demonstrate the contribution of these different approaches to improve energy efficiency. Therefore, this paper attempts to provide a contribution in this field by presenting both: an overview of the climatic contrast between the northern and southern parts of Portugal and its influence on the type of approaches adopted by vernacular architecture; their potential contribution to passive building design; and the results of a study on the effects of passive cooling strategies on the control of indoor temperature and humidity of a building during summer.

THE CONTRIBUTION OF VERNACULAR TECHNIQUES TOWARDS ENERGY EFFICIENCY

In the past, due to the lack of advanced technological systems for the maximization of comfort, buildings were built using passive systems. While simple and clever, these were based only on the available endogenous resources and on a range of criteria such as: geographical characteristics; insolation; orientation; geometry; form; and materials, among others (Coch, 1998; Oliveira & Galhano, 1992).

The relationship between the built environment and the natural environment is well described by the Roman mythological concept of the *Genius Loci* and has primal importance on buildings' conception and thermal performance. The significant differences between the way house-construction developed in northern Africa and northern Europe, for example, demonstrates that this was not a random process; similarly, in Portugal, there is a considerably difference between the houses from north and south.

Several quantitative studies on the thermal performance of vernacular buildings conducted in different parts of the world have shown that vernacular buildings achieved acceptable comfort standards throughout much of the year just using passive strategies, in some cases indoor temperatures remaining almost constant (Cardinale, Rospi, & Stefanizzi, 2013; Martín, Mazarrón, & Cañas, 2010; Shanthi Priya, Sundarraja, Radhakrishnan, & Vijayalakshmi, 2012; Singh, Mahapatra, & Atreya, 2010). The results support the idea that passive strategies are in many cases feasible for use in contemporary buildings and that they could contribute to reduce buildings's energy demands for HVAC.

VERNACULAR ARCHITECTURE IN NORTHERN AND SOUTHERN PORTUGAL: STRATEGIES TO SUIT THE CLIMATE

Vernacular architecture in Portugal, as in other countries all over the world, is influenced to a great extent by geographical location. Climate and other geographical features account for differences between the various types of vernacular constructions found in the different regions of this country.

Continental Portugal is located between latitudes 37º and 42ºN in the transitional region between the sub-tropical anticyclone zone and sub-polar depression zone. Beside latitude, the most important features affecting the climate of the territory are orography and the influence of the Atlantic Ocean (Santos, Forbes, & Moita, 2002). With regard to relief, the highest peaks rise to a height of 1,000m to 1,500m, except for the Estrela Mountains, whose highest point is just under 2,000m.

Even though it is a small country, Portugal is a territory of contrasts. In spite of the fact that the variation in climate factors be rather small, it is sufficient to justify significant variations in air temperature and precipitation, such as (Santos et al., 2002):

- Air temperature – in winter the average minimum temperature varies between 2ºC in the mountainous interior zone and 12ºC in the south zone of Algarve; in summer Summer: the mean maximum temperature vary between 16ºC in Serra da Estrela and 34ºC in inner central region and eastern Alentejo.
- Precipitation – in the highlands of the northwest region the mean annual accumulated precipitation is above 3000 mm, one of the wettest zones in Europe; in southern coast and in the eastern part of the territory: the average amount of rainfall is in the order of just 500 mm; southern interior has a Mediterranean climate, well known for its vulnerability to climate variability, namely to droughts and desertification.

To suit different climate conditions Portuguese vernacular architecture developed specific mitigation strategies. In a general form, as shown in Figure 1, it is possible to verify that in the northern part of the country the adopted strategies aim to increase heat gains and to reduce indoor heat losses during winter, while in the south the strategies are more focused on passive cooling during summer.

In order to respond to cold winters, reducing heat losses and taking advantage of solar radiation, vernacular builings from the north frequently used thatched roofs – due to their insulating properties – to reduce heat losses, and south-facing balconies to take advantage of solar radiation. The glazed-balconies are a feature of the architectonic identity of the Beira Alta region and, due to the advantages they bring many are still in use today. They are usually facing between south and west so that they receive the highest number of hours of sunshine and a high level of radiation during the winter, while affording the best shelter from the prevailing winds, as shown in Figure 1 (a). The use of this kind of structures is feasible in refurbishment projects with energy efficiency purposes, as demonstrated at the Residential complex in Dornbirn, Austria, where residents' heating bills have been significantly reduced (Küess, Koller, & Hammerer, 2011).

In the south of the country, in order to minimise heat gain, several techniques were developed, such as (Figure 1 (b)): reducing the size of doors and windows; the use of a high thermal inertia building systems; the use of courtyards (patios); and the use of light colours in order to reflect the excess solar radiation. The effect of these passive cooling strategies on the thermal performance of buildings is described in the case study in the following section.

The abovementioned strategies are relevant to the debate on energy efficiency in buildings because they are aimed at reducing energy consumption and increase the comfort level for occupants by passive means. Despite the advantages of the presented passive strategies, for the Portuguese context there is a lack of quantitative data on the effectiveness of these approaches on the thermal performance of vernacular buildings in different climate zones. Nevertheless, the interpretation of the results of studies conducted in other European countries points to some techniques of Portuguese vernacular architecture being effective and having the potential for use in contemporary buildings.

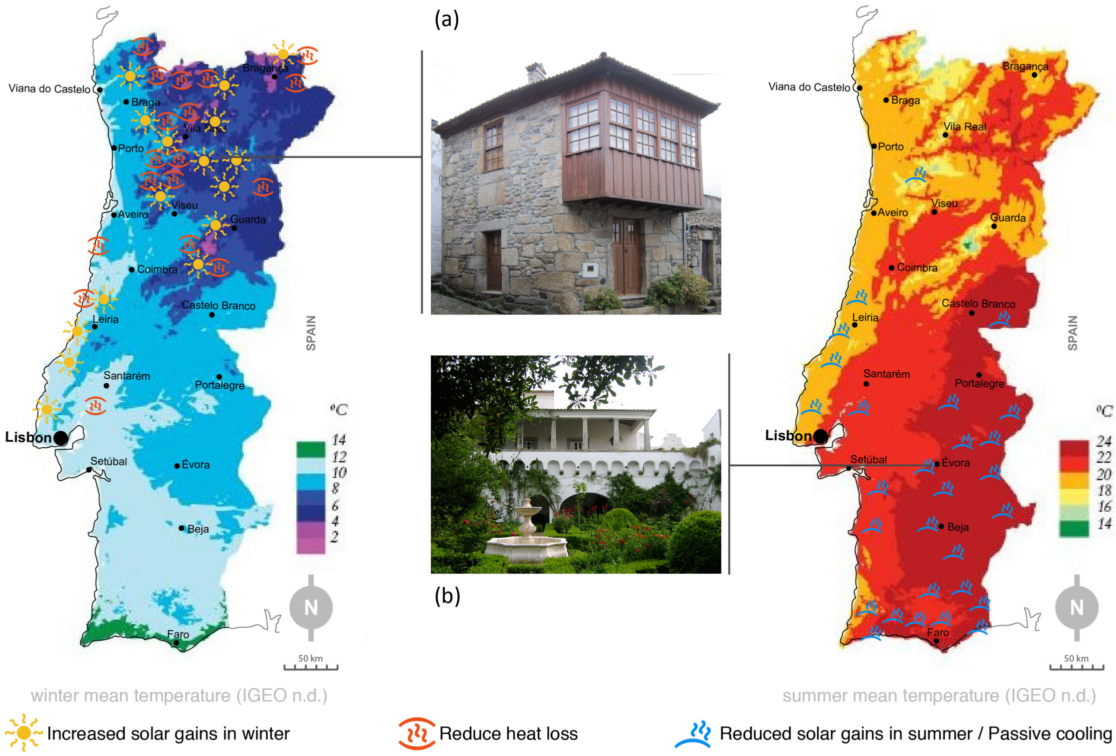

Figure 1 Winter / summer mean temperature maps (IGEO, n.d.) and vernacular strategies distribution; (a) glazed-balcony building; (b) building with a courtyad (*patio*).

PASSIVE COOLING STRATEGIES EFFECT IN THERMAL PERFORMANCE OF A CASE STUDY

Aim and description of the case study

The study presented in this paper is aimed at a quantitative analysis of the contribution of passive cooling strategies, a vernacular approach used mainly in the south of Portugal (Figure 1), in the control of indoor temperature and humidity during the summer to achieve comfort conditions.

The case-study is situated in the historic city centre of Évora, a city located in southern interior Portugal (latitude 38º34’N, longitude 7º54’W). The climate in Évora is Mediterranean temperate (Csa – according to the Köppen climate classification), with hot and dry summers and high temperatures during July and August (with maximum temperatures of 30°C to 40°C, occasionally reaching 45°C) (AEMET & IM, 2011). In July and August severe drought is normal and rainfall is rare, with an average total precipitation of 8,6 and 6,6 mm, respectively (AEMET & IM, 2011).

The monitored building has an L shape, with the façades facing the courtyard oriented to SE and SW, as shown in Figure 2a-b. The courtyard has plenty of vegetation and in which two trees offer considerable shade for the building. The building has two storeys and a total area of approximately 900m^2: the ground floor houses the kitchen, a bedroom, and various storage spaces; on the upper floor there are living rooms and other bedrooms.

The *in situ* measurements were carried out in the ground floor (Figure 2a), which have the following construction features: traditional brick vaulted ceilings, ceramic tile finished floors, lime mortar finished walls and single glazed wooden windows. The average wall thickness of the building is about 100 cm. It was not possible to rigorously determine the composition of the walls but, so taking into consideration that this kind of buildings were usually built with rammed earth or massive brick masonry, it was estimated that the heat transfer coefficient (U-value) is of about 1,00 W/m2.ºC. The floor area of the monitored spaces is approximately of: kitchen – 33m^2; bedroom - 17m^2; courtyard - 600m^2.

Methodology and equipments

The effect of passive cooling strategies in the control of the indoor temperature and humidity of the building was quantified through *in situ* experimental measurements. Two physical parameters were quantified: air temperature (ºC) and relative humidity (RH %). For this purpose, were used three equipment with an internal sensor to measure temperature and relative humidity of the air. It has a measuring range between -35 to 70ºC and an accuracy of ±0.9ºC. Readings recorded can be downloaded to a PC.

Field measurement involved the positioning of units inside and outside the house: one in the courtyard and two inside, in the ground floor: one in the room adjacent to the courtyard (the kitchen) and the other in the bedroom (Figure 2a). Data was recorded continuously over the period from 17th to 26th July 2007; data from the different sensors was recorded at 30-minute intervals. Secondary data for the study was collected at the Geophysics Centre of Évora for the same time period.

Figure 2 a) Ground floor plan showing the position of measuring instruments; b) View of the courtyard (*patio*).

Analysis of results

Indoor air temperature, both in kitchen and bedroom, varied slightly, remaining nearly constant, while in the courtyard there were great fluctuations in air temperature throughout the day (Figure 3). The high thermal inertia of the building is the most probably reason for this, but the presence of abundant vegetation in the courtyard also contributed towards reducing direct heat gain through the envelope by providing shade. In order to provide an understanding of the effectiveness of different passive cooling techniques used in the building, these results were compared with the data recorded in the city centre during the same period. This showed not only the importance of the thermal inertia for reducing variations in indoor temperature but also the role of the courtyard in substantially reducing air temperature around the building. An analysis of recorded data shows that air temperatures in the courtyard always remained lower than those recorded for the city centre, especially during peak periods of heat, with a maximum difference of around 9ºC, as shown in Figure 3. It may also be concluded that this vernacular approach also allows for a delay of approximately 90 to 150 minutes between the moment at which the temperature in the courtyard starts to rise and that at which peak temperatures are reached in the city centre. An analysis of the chart in Figure 3 shows that during daytime, in the city centre, outdoor relative humidity reaches a minimum of about 20% whereas the maximum temperature is nearly 40ºC. For the same period, in the courtyard, minimum relative humidity is nearly 30% and the maximum temperature is about 30ºC. A possible reason to explain the lower air temperature in the courtyard is that the existing vegetation does not allows that this area contributes for the local heat-island effect (Figure 2b). Additionally, both the abundance of vegetation and the presence of a water fountain contribute to the evaporative cooling of the courtyard, thus raising the relative humidity and diminishing the air temperature. Another plausible reason for this difference is that cool humid air, which is consequently dense, remains in the courtyard during the early hours of the morning, until is warmed by the sun. In this confined space, the air takes longer to gain heat than the air in the city centre, thus its temperature remains lower and its relative humidity higher than the air in the city centre during warm periods.

Indoor relative humidity shows slight fluctuations throughout the day with an average of around 50%, the most suitable level for human health and comfort (Morton, 2008). This difference between indoor and outdoor relative humidity can be explained by the use of materials that contribute to the regulation of indoor humidity. Indoor wall surfaces and ceilings are covered with lime plaster, with a thickness of about 3cm. This material regulates the quality of the indoor environment, as it is not only permeable to water vapour but also contributes towards moisture buffering (Berge, 2009), i.e. it moderates changes in relative humidity by absorbing moisture from the surrounding air and, when the air is less humid, giving off absorbed moisture.

In what concerns the assessment of the thermal comfort conditions indoors, was applied an adaptive model of thermal comfort, since this is the most adequate model for naturally conditioned areas, and used a psychrometric chart representing Évora's climate conditions and the adaptive comfort range for July. Due to high fluctuations in outdoor temperature and humidity between night and day, the thermal conditions for each indoor space were represented separately for day and nigh. Analysing the results it is possible to conclude that both kitchen and bedroom spaces have thermal conditions within the limits of the adaptive thermal comfort range for summer in the majority of the days without any mechanical cooling system, as shown in Figure 4. Only the bedroom did not reach the comfort conditions in two days. However, is very close to the comfort limit.

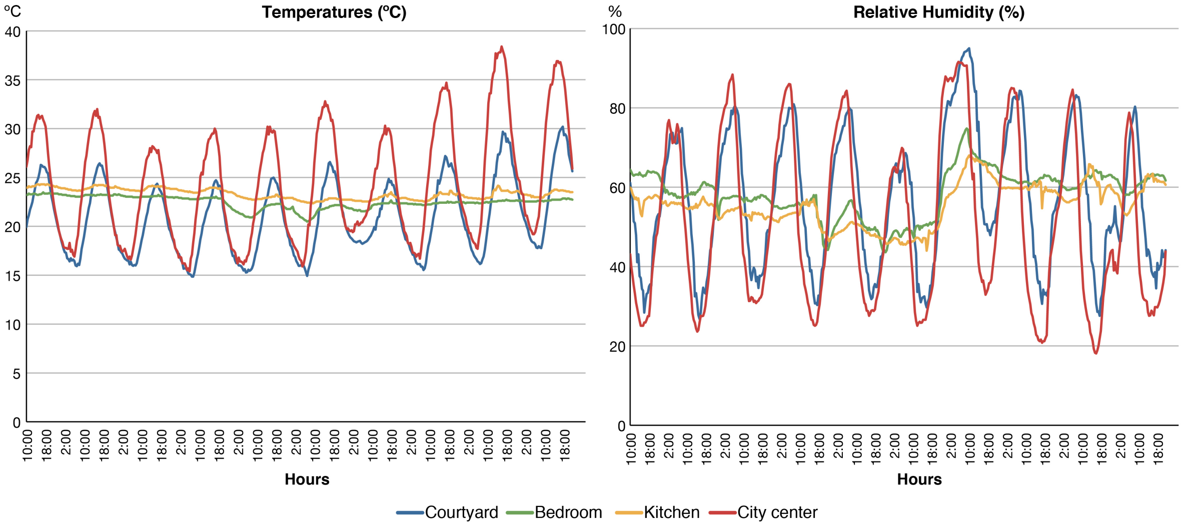

Figure 3 Indoor and outdoor temperature and relative humidity profiles.

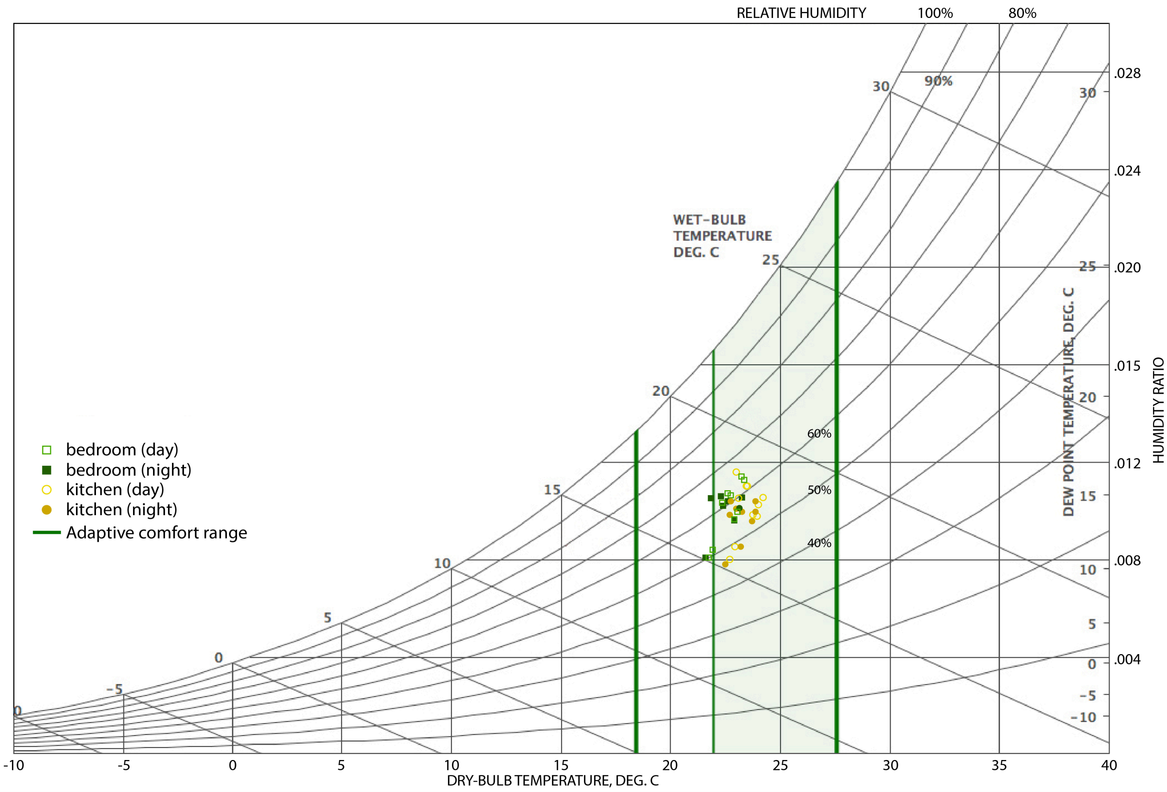

Figure 4 Psychrometric chart for Évora representing the indoor comfort conditions in the case-

study, applying the Adaptive Comfort Model in ASHRAE 55 (2010) (Chart adapted from: "Climate Consultant 5.5," 2014)

DISCUSSION AND CONCLUSIONS

Vernacular architecture is the paradigm of the interaction between architecture and climatic conditions. The techniques presented in this paper, due to their simplicity and pragmatism, have great potential for use both in the design of refurbishment projects and the construction of new buildings. For example, the passive cooling strategies employed in the south of the country, as shown in the case study in Évora, are simple to implement and can improve indoor comfort conditions in buildings during the summer season. Our findings show a difference of 7ºC and 16ºC between indoor temperatures and the peak outdoor temperatures (recorded in the courtyard and in the city centre, respectively) and the psychrometric chart showed indoor spaces within the thermal comfort limits during all the monitoring period, which means that such a vernacular approach has great potential for decreasing energy consumption by means of active cooling systems. These results are achieved by combining several passive-cooling strategies, such as: whitewashed walls; small exterior doors/windows; high thermal inertia walls; and courtyards or *patios*. In these strategies, the two last have considerable influence in indoor climate. The courtyard revealed to have a large influence on the creation of a microclimate near the building, with air temperatures remaining lower than those recorded for the city centre, with a maximum difference of around 9ºC. It is likely that these features affect the thermal performance of the building during the winter. However, taking into consideration the regional climate classification considered in the Portuguese Regulation for Energy Performance of Buildings (DL118/2013, 2013), the most difficult issue to solve in this region is the hot summer period.

With an opposite purpose, the balconies in Beira Alta provide an efficient mean of increasing solar gains and preventing heat loss, are easy to install and play an important role in minimising heating requirements. It may also be concluded that these strategies are perfectly adapted to the local area in which they were developed and there is no negative aesthetic impact on buildings.

Vernacular knowledge on passive strategies is relevant when current buildings are known to have a high level of energy consumption for providing air conditioning. It is imperative that priority is given to building design that adopts passive methods for controlling the indoor climate, limiting mechanical systems no more than a backup role, to be used only when the passive strategies are not sufficient for meeting the comfort needs of occupants. This paper assesses in holistic terms this architectural manifestation in the light of current knowledge in order to seek scientific justification for the principles of vernacular architecture and validate and promote its use in the future. However, there are limitations to this study and some aspects are only discussed qualitatively. Further studies are required to provide quantitative assessments in order to generate specific scientific information about the thermal performance of vernacular buildings in Portugal. More accurate information about the contribution of passive vernacular solar strategies would be useful for architects and engineers concerned with climate-responsive and energy efficient buildings and therefore could provide a contribution to the sustainability of buildings.

ACKNOWLEDGMENTS

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The influence of culture on energy consumption in Aboriginal housing in arid regions of Australia

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ABSTRACT

This paper examines both the technical and sociocultural aspects of Aboriginal housing in hot dry climates, posing the question: can domestic living patterns and preferences be harnessed to reduce domestic energy consumption? The colonial history of housing Aboriginal people in Australia is rife with precedents that are unsuccessful on multiple levels. Research has highlighted the frequent mismatch between modern housing types and the sociocultural traditions of Aboriginal households. In arid and semi-arid regions, the majority of Aboriginal housing is poorly designed for the climate, yet this aspect of shelter has received limited scholarly attention. The design of bioclimatic houses that support cultural patterns is still an architectural challenge, complicated by diverse historical and economic conditions. Additionally, the increasing cost of energy causes economic stresses for public housing occupants. Current climate change models for Australian arid regions predict increasing temperatures and less predictable rainfall patterns, which provide further challenges for low-energy housing design. Using recent survey data on Aboriginal housing in Northwest Queensland, this paper examines the design implications of using both sociocultural and technical factors to improve living environments and reduce energy consumption. The integrated design of buildings in landscaped yards can both mitigate overheating and support socio-cultural practices that affect overall residential energy consumption. Despite a general consensus on the significance of external living environments in the literature, there is lack of evidence from research that measures culturally derived adaptive strategies to reduce residential energy consumption in Aboriginal housing.

INTRODUCTION

In the arid and semi-arid regions of Australia, a large proportion of the Aboriginal population face problems associated with socio-economic disadvantage, the high cost of domestic electricity supply, high energy demand, and predicted changes to the climate. These problems are compounded by housing and yards that are poorly designed for the current climatic conditions. In the remote regions, within the last century, the transition to sedentary Western style housing has disrupted and transformed social and cultural practices related to Aboriginal domestic living patterns. Since the 1970s, when housing Aboriginal people became a political concern for Australian governments, researchers have documented the dilemmas and difficulties of designing culturally appropriate housing (Heppell 1979; Memmott 2004; Reser 1979; Ross 1987). This area, and Aboriginal housing generally, remains under-researched (Long, Memmott & Selig 2007), partly due to the diversity of Aboriginal groups, demographic change and significant socio-cultural changes influenced by multiple factors.

Only recently has research attended to questions of thermal performance of Aboriginal housing and energy use, partly as a result to climate change studies (Duel et al. 2006; Martel et al. 2012; Horne et al. 2013). There is a need for further studies that purse an integrated approach to research that attempts to measure housing quality and performance, and record and analyze behaviours that affect energy use. This aligns in one of the gaps in data identified by the IPCC (2014:67), which recognized the need for "Improved and more comprehensive databases on real, measured building energy use, and capturing behaviour and lifestyles are necessary to develop exemplary practices from niches to standard."

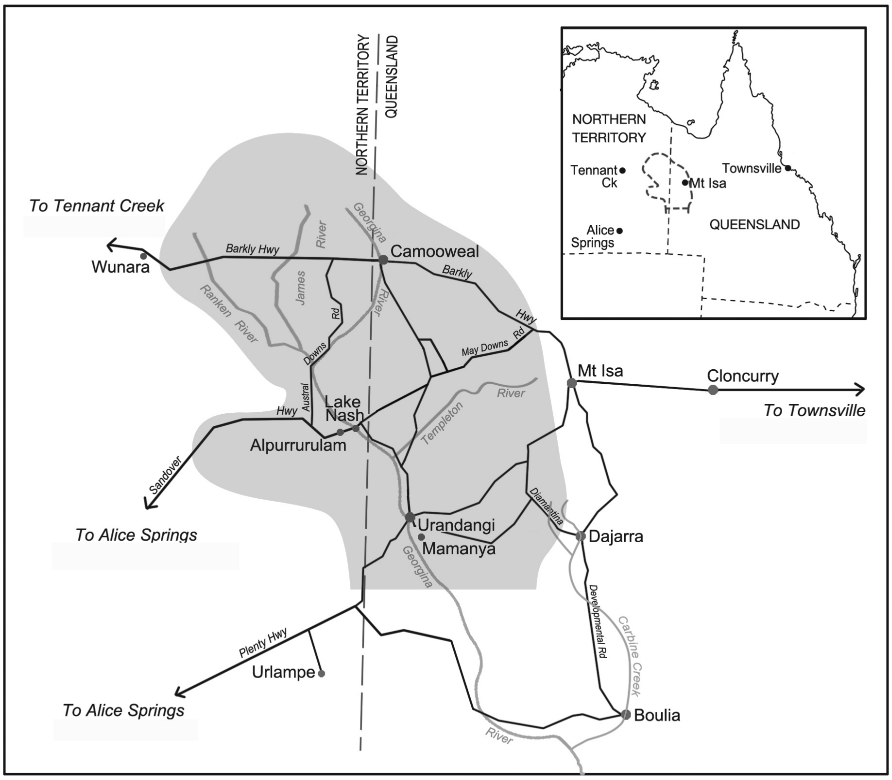

Figure 1. Map of the upper Georgina River Region showing settlements Dajarra, Urandangi, Camooweal and Wunara examined in the research on climate change.

Using data from different sources, this paper examines the potential for synergies between low-energy housing design and Aboriginal cultural practices. It also identifies behaviours and external factors that challenge sustainable domestic architecture in remote semi-arid and arid regions. This raises the primary question: once identified, can socio-cultural patterns and preferences be used in design strategies for low-energy domestic living environments? This question is particularly pressing given the added challenge of climate change in the arid regions of Australia, where new approaches to housing design are necessary for mitigation strategies in both Aboriginal and mainstream housing (Wang et al. 2011).

METHODS

This papers draws on research that examined climate change Aboriginal people and in the Georgina River Basin, a semi-arid region in northwestern Queensland, extending across the Northern Territory boarder (Figure 1.). In 2011 and 2012, an interdisciplinary study of Aboriginal adaptation to climate change was conducted in four towns in the region (Memmott et al. 2013). Surveys were used to ask 32 questions (quantitative and qualitative) about the informant's experience and use of the built environment and utilities. This included housing, domestic behaviour patterns and preferences, water supply and electricity, with some questions related to climate. These data and observations of Aboriginal houses and yards are compared with the literature on Aboriginal housing design, complemented by evidence from architectural practitioners working in the field. Data on the planning, construction and performance of Aboriginal housing in remote areas draws on post-occupancy evaluations, housing assessments and the collective observations and records of an interdisciplinary research centre with four decades of experience in the field. A number of researchers have conducted research in the upper Georgina River Region for over a decade with a particular focus on the built environment and the delivery of services (Long & Memmott 2007; O'Rourke 2011). In the small town of Dajarra, Long (2005) documented socio-cultural practices in an extended ethnographic study of Aboriginal people's living environments in the settlement.

CLIMATE AND HOUSE CONSTRUCTION

The upper Georgina River Region is characterized by a hot dry climate with mild winters, although toward the north of region the summers are more humid. The rainfall varies across the region, with a general decrease in precipitation moving south away from the influence of the northern summer monsoon: from wet summer/dry winter (mean annual rainfall of 401 mm in Cammoweal) to an arid climate (264 mm/annum in Bouila). Landscapes are predominantly grasslands in the north with deserts in the south. In Cammoweal, the annual mean maximum temperature is 32℃ and in mean minimum is 17.6°C.

Climate change models for the region predict temperatures to increase in arid regions with a greater frequency of extreme heat events (CSIRO 2007). A recent review of the Australian climate data (CSIRO 2014) describes a significant warming trend across the arid and semi-arid regions of the continent. This includes increases in the duration, frequency and intensity of heatwaves since 1950. Seven of the ten warmest years on record have occurred since 1998. In 2013, the region experienced its warmest spring on record. Overheating is the main challenge with housing in the region, with mean maximum temperatures averaging around 38℃ across the four summer months. Winter temperatures require heating for thermal comfort, and Aboriginal people in the arid regions are sometimes more concerned about cold conditions that hot weather (Thorne et al. 2013).

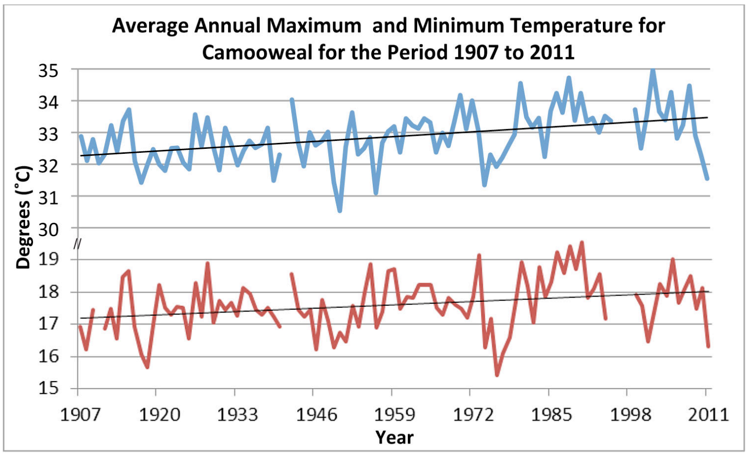

Figure 2. Climate profile for Camooweal. (Source Memmott et al. 2013)

In his analysis of the regional climate and housing design, Szokolay (1990) advised that cross-ventilation cannot be relied on for cooling; insulated thermal mass walls are able to exploit the relatively high diurnal variation with nocturnal ventilation, and benefits from either passive or mechanical evaporative cooling. He also recommended slab-on-ground construction with full shading of walls all-year-round. Deep verandahs are generally recommended for cultural reasons, although fixed shading can limit the use of thermal mass for heating in the regions with colder winters (Duel et al. 2006:45). Recent studies (Wang et al. 2010, 2011) of heating and cooling energy requirements for residential buildings across different Australian climatic zones predict that, under current models, climate change will significantly increase the cooling loads in arid zone housing.

In our survey of housing in four settlements in the Georgina River region, 72% of the participants (N=68) agreed that their house was too hot in summer and similar numbers agreed that their houses were too cold in winter. Over 70% used air conditioning to 'get through summer', although the preference to live in an air-conditioned house was less than 50%. In Dajarra, about one third of the houses had evaporative air conditioners and one third had refrigerated air-conditioners—all were retrofitted to the housing. The state-wide use of residential refrigerated and evaporative air conditioners has increased significantly in the past 20 years, with only one third of Queensland households not using air conditioners in 2009 (ABS 2010).

ENERGY PRICE AND POVERTY

Electrical energy is the primary source of domestic energy in the study region with all but a few houses connected to a distribution network. Between 2003 and 2013 in Australia, household electricity costs increased on average by 72% in real terms (Swobada 2014). The increase in the study region was 73%, with additional price increases of 20.4% in 2013-2014 and 13.6 % announced in May 2014 (AER 2013:131). This increasing cost in electricity supply has placed considerable financial burden on Aboriginal households in the remote regions where low rates of employment limit disposable income. In a 2008 survey, expenditure on electricity in Dajarra ranged from AUS $2, 400 to $6,000 per annum for Aboriginal households of varying size in one settlement (O'Rourke 2011). For many Aboriginal people occupying remote public housing, price rises in electricity increase vulnerability to climatic extremes, and particularly during heatwaves (PWC 2012).

In remote settlements, Aboriginal people have increased dependency on electrical energy although surveys of housing show that refrigerators, air-conditioners and electric heaters are at the lower end of energy efficiency. In our survey, 55% worried about paying bills and the same number of participants had changed the way they used household appliances to reduce electricity usage. A significant number (37%) had changed the way they lived in their house and yard due to extreme weather events.

HOUSING BACKGROUND

The change from mobile hunter-gather patterns of dwelling to more sedentary living conditions in remote regions of Australia varied with the history and circumstances of the colonial frontier. Aboriginal dwelling practices follow three historical phases that were often overlapping and uneven across the last 150 years: 1. In traditional or pre-colonial campsites a repertoire of shelters largely related to seasons were structured around spatial practices: windbreak and shade structures were used for most of year, with thatched domical dwellings used during cold and wet weather; 2. Adaptation of building traditions to more sedentary settlements often on the margins of colonial towns, pastoral properties, and government or missionary reserves; and, 3. The first substantive investment in state-supplied Aboriginal housing began in the late 1960s.

Although the involvement of architects in housing was initially promising in the 1970s (Heppell & Wigley 1981), direct participation in design has been marginal. In remote settlements, the housing stock varies in age and type, ranging from transportable homes, prefabricated housing, to a variety of mainstream housing, often standardized designs. A substantial proportion of Aboriginal housing in remote areas is of poor quality and requires either significant upgrade or replacement (Hall & Berry 2006; Pholeros et al. 1993). Remoteness—defined by distance to a service centre—is a significant factor in the design, delivery and maintenance of housing (Hall & Berry 2006:100). Transportation to remote or settlements limits construction choices and the cost of both labour and building materials escalates with distance from major coastal cities. A correlation between remoteness and continuities of pre-colonial Aboriginal socio-cultural practices adds to complexity of housing design in remote settlements.

Memmott (2003) identified three approaches to Aboriginal housing design that vary in their primary objectives: culturally appropriate factors, design for environmental health, and building procurement and delivery methods. These overlap but design for environmental health has had the largest influence on design standards (FACSIA 2007). There are notable exceptions of housing that provides architecture responsive to socio-cultural practices in remote regions of Australia (Dillon & Savage 2003; Memmott 2001, 2004). But within the literature, low-energy housing, for either socio-economic reasons or concerns about climate change, has received less emphasis than housing for cultural or health factors. There are few empirical studies of the thermal performance or energy use in Aboriginal housing: Duel et al. (2006) modeled thermal comfort of standardized designs in desert communities and Martel and Horne (2013) examined house designs in hot/humid area of northern Australia.

Settlement morphology and conventional housing in arid regions of Australia are not derived from historical or vernacular building traditions suited to hot/dry climates. Residential building types are largely detached suburban housing (variations on the bungalow), which continue to establish patterns and expectations for mainstream residential buildings. Courtyard type housing, for example, has few precedents in arid Australia for either Aboriginal or mainstream housing. Two examples by architects in the 1970s failed for a number of cultural and functional reasons (Heppell 1979; Heppell & Wigley 1981:157). Remote Aboriginal clients are wary of experimental housing design and preferences for conservative, mainstream architecture can conflictwith preferred living patterns (Memmott 2003).

SOCIO-CULTURAL FACTORS AND IMPLICATIONS FOR HOUSING ENERGY USE.

Research and evaluation of both mainstream and self-constructed Aboriginal housing has identified a range of behaviours and social practices that are relatively consistent across remote settlements in semi-arid regions (Memmott 2003). We need to be cautious about accepting generalizations for diverse groups and changing demographic profiles, but the following factors either directly or indirectly influence residential energy use.

Mobility and the use of houses

High intraregional mobility is a consistent and common practice of people Aboriginal in remote and regional areas across the country and this factor directly affects the occupation of housing with implications for domestic energy use. Research on mobility in three towns in the study region in 2006 found that about one third of Aboriginal households contained visitors, a proportion consistent with other studies (Long & Memmott 2007:3). Cultural and social factors (the maintenance of kinship relationships) and service needs are main reasons for the high mobility.

Across Australia, Aboriginal household numbers are significantly higher than the mainstream household. High household numbers are related to general housing shortage in remote areas, population growth, socioeconomic disadvantage and cultural preferences (Memmott et al. 2012). High mobility also causes household numbers to fluctuate. There is a growing literature on overcrowding Aboriginal households yet there is little direct evidence of the relationship between numbers and energy use. High and fluctuating household numbers present challenges to designers and need to be considered in the assumptions required for thermal modeling of Aboriginal housing.

Unconventional use of housing by Aboriginal people is common in remote and urban settlements. Living rooms are used at night for sleeping (Long2005:223) and bedrooms can be occupied by relatively large numbers (2013). Social and technological change has also increased energy intensive activities such as television and computers, particularly for younger generations, yet the effects on housing use is underexplored. Surveillance of the community and environment was a determinant in the architecture and spatial arrangement of traditional camps yet it is common for windows to be closed and heavily screened. This may relate to privacy but in remote communities the practice may also relate to a fear of the supernatural and sorcery (Dillon & Savage 2003). In areas where this practice is prevalent, the use of windows for either diurnal or nocturnal ventilation needs to be reconsidered—occlusion of windows renders them ineffective for either daylighting or venitation (per. comm. Finn Pederson 2014).

External living

The literature on Aboriginal housing indicates a strong preference living outdoors during the day, and sleeping outside the house has shown to be been common in remote settlements (Long 2005; Memmott 2003; Musharbash 2008; Pholeros et al. 1993). Both socio-cultural practices and thermal comfort influence these behaviours. In summer, shaded areas outside the house, mostly from trees but also purpose built shade structures, are used in preference to the house interior (Dillon & Savage 2003). External living environments, which include verandahs, also enable social and environmental surveillance, including the monitoring of weather and seasonal indices.

In remote areas, adapted forms of pre-colonial shelter types continue to be constructed in yards to support socio-cultural practices. Variations on the windbreak are used extensively in yards and often associated with fires for warmth or cooking purposes: firewood piles are common in yards in the study area with the elderly often supplied by family. In the study region, and arid-zone settlements generally, traditional thatching materials are used on shade structures, but certified uses of such materials are limited.

Figure 3. Housing in Dajarra that show little modification of the yard and a self-constructed windbreak used for cooking and other activities. June 2013. (Photographs author).

Aboriginal residents use conventional (mainstream) internal kitchens but a range of traditional cooking activities occur outside the house in open fires and wood-fueled stoves (Long 2005). Long has traced the continuity of these traditions in the study area, recording the additions and alterations to rental housing to make external cooking areas. Thermal comfort was an additional reason for external cooking. In survey questions about adapting to increasing energy costs (Memmot et al. 2013), almost of quarter of respondents preferred to cook outside on wood fires.

Design guides (FACSIA 2007) and good architectural practice (Dillon & Savage 2003) recognize the use of external living environments but exemplars of yard design are rare and not recorded in the study region. Our research shows that gardening practices vary and landscaping around housing for shade depends on the householder. In Dajarra, comparisons of aerial photographs show an increase in vegetation cover over the last three decades. Garden irrigation is also used for evaporative cooling effects in summer but garden maintenance results in very high residential water use in settlements with unreliable water supplies (O’Rourke 20110).

With limited empirical data, it is difficult to gauge whether outdoor living activities are diminishing as people adapt more to houses and become accustomed to air-conditioning. In survey questions on adaptation of living environments to increasing hot weather, the most common answer was to use trees and landscaping. A recent post occupancy evaluation of Aboriginal housing in Alice Springs (CAT 2013), suggested that improvements to yards were more desirable for tenants than alterations to the house. Although the potential of landscape elements to improve thermal performance of residential buildings has long been recognized in arid region design in Australia (Aitchison 1962), there is a wide gap in studies of the actual and potential contribution of microclimates to low-energy housing, particularly in the reduction of cooling loads. Selection, testing and evaluation of xerophytic plants are also necessary given climate change and problems with water supply in arid regions.

With the high cost of construction, landscaping of yards is rarely delivered in remote public housing projects. Cost, household mobility and resources limit ability of the tenants to improve landscapes around remote public housing. Despite these impediments, a range of gardening practices can be identified in the study region. Design improvements to residential landscapes benefit from the participation of household, in both maintenance and involvement in the design process.

CONCLUSION

Studies in the Georgina River Region found that vulnerability to climate change was related to poor quality housing and increasing energy prices. Low-energy housing is required for socio-economic reasons and the viability of remote Aboriginal settlements, in addition to low carbon imperatives. In the semi-arid and arid regions of Australia, modeling software demonstrates that both existing and new residential buildings will need substantial changes to building envelopes to achieve existing levels of thermal comfort without large increases in energy intensity (Wang et al. 2011). Harvey's review of low-energy buildings (2013:303) suggests that high performance housing requires "significant additional investment costs, with simple payback times of 20–30 years or more." His survey shows that high levels of skill, from integrated design processes to construction, can produce economical low-energy buildings.

Although integrated design and technologies can inform approaches to Aboriginal housing, the literature emphasizes knowledge of domestic social and cultural behaviours as a prerequisite for cross-cultural design. Limited but relatively consistent evidence presented in this paper suggests that certain socio-cultural practices provide a level of passive thermal comfort. This is particularly the case with the use of external living environments. These practices present opportunities for synergies between behaviour and passive or low-energy design. Landscape design for residential microclimates in the arid region supports current cultural practices and has potential to reduce the energy intensity of housing. In contrast, mainstream housing, reliant on air-conditioning, can work to undermine domestic cultural practices that are inherently sustainable.

It is a challenge for researchers to devise methods to record behaviours and preferred practices that influence the use of housing and yards over different seasons in remote areas. This does require an ethnographic strand to the research. In different settings, social and cultural change affects the currency and relevance of existing data. Data is also deficient in the measurement of energy use and the thermal performance of existing housing and yards as well as data on new approaches to design of both the internal and external living environments in arid regions.

ACKNOWLEDGMENTS

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Evaluation of Environmental Control of Transitional Microclimatic Spaces in Temperate Mediterranean climate

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ABSTRACT

Mediterranean architecture is characterised by the presence of transitional spaces in which thermal conditions are intermediate between the inside and the outside ones. It is important to analyse these spaces because they act as climatic moderators with a strong social role at the micro scale level.

This study focuses on a particular type of transitional space that morphologically is located at the border of a building, usually called porch. The geometry of this space influences the effect of solar radiation as a source of heat in the space and for the building facing on it. However, their potential in terms of thermal comfort especially in summer season is in contrast with the need of solar gains in winter, daylighting and visual contact to the outside. The importance of integrating these aspects is generally underestimated by designers.

Aim of this study is to define the potential of environmental control of these transitional spaces and, in particular, how they can balance the requirement of a shaded area and the need of natural lighting inside the building. The effects of a porch orientation and proportions are analysed to compare how different configurations modify the transitional space performaces. These evaluations are performed with simple tools, which take into account the impact of direct and diffuse solar radiation.

The analysis is still in progress but the most important finding of this paper is to present a method of evaluation that enables the architect to do early stage considerations according to the user requirements and the external constraints of the context.

INTRODUCTION

Mediterranean architecture is characterized by a great diffusion of transitional spaces (called also intermediate or semi-open spaces) that have intermediate thermal conditions between the indoor and outdoor environment. Historically their role as climatic moderators makes them an extension of living space and a place that favour social relations.

These spaces have always existed in different countries with specific features according to the culture and the climate. The benefits they provide make them interesting to investigate.

Intermediate spaces were largely used in the history of the Mediterranean countries where they originated and developed different configurations as porches, patios, loggias etc. especially in the

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northern latitudes where the climate is more temperate and variable through the year (presence of hot summers, cold winters and middle seasons). These intermediate conditions imply the necessity of adapting the building to variable external dynamic stresses, combining the necessity of summer cooling and winter heating. For these reasons, transitional spaces are considered very important passive strategies, especially for their role in moderating the effect of direct solar radiation at a microscale level.

Since a complex network of different public spaces constitutes the structure of Mediterranean cities, the presence of intermediate spaces such as covered streets creates semi-public environments that act as unifying elements and promote a gradual transition between areas with different functions and levels of privacy. The potentially comfortable area they provide makes possible to experience protected zones where to sit, relax and enjoy the surroundings.

They are still built today but often using new materials and formal solutions with the only aim of enhancing the building exterior appearance. In fact, the advent of mechanical systems to control climate in modern buildings led to a standardized architecture with little use of passive strategies. Thus, the results often demonstrate a lack of environmental consciousness. This paper tries to clarify the environmental impact of these traditional forms and explains a method that enables the architect to do first conscious design considerations balancing the different needs required by a specific project.

TRANSITIONAL SPACES

Although transitional spaces have always played a significant role in moderating climate, it’s difficult to completely define their use because of their nature of being always “in between” different conditions (external/internal, public/private etc.). However, they can be classified in categories depending on their relation to the building.

From literature review (Chun et al., 2004; Coch, 2008; Maragno, 2010) there are: the “central type” totally enclosed by building’s walls and opened to the sky such as courtyards, patios and atria and the “perimeter type” covered and located at the border of a building such as porches, loggias and balconies.

Their value in climatic control is recognized from the Greek and Roman architecture mostly because they provide protection from undesired sun radiation, wind and rain, creating habitable semi-open spaces. The two types are sometimes integrated or used in a sequence increasing their value. For example, the Roman “domus”, the most typical Mediterranean residential housing type, is constituted by these different types of space: the impluvium and the court (central) and the peristilium (perimeter).

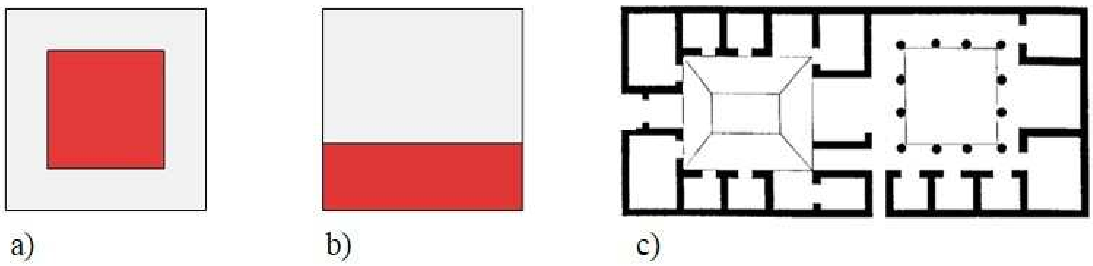

Figure 1 (a) "central type", (b) “perimeter type” and (c) the Roman “domus”.

The advent of the glass in the modern architecture made possible the transformation of these two traditional types of transitional spaces in real “thermal buffer spaces”: the central type became an atrium and the perimeter type a greenhouse. The glazed solution increases the thermal effect but loses partially the relation to the outside that remains only visual. This is an example of how the new technology transforms traditional architectural elements in a way that potentially increases the climatic control but more specific knowledge and a more conscious design is required to avoid undesiderated effects of overheating.

The shading effect

This work is based on the hypothesis that the microclimatic characteristics of transitional spaces influence people's behaviour and their propensity to use such spaces (Dessì, 2007). The qualities of these spaces are visible at a micro-urban level because they create microclimatic environments that enhance activities and provide social interaction. They can be seen as a comfortable extension of the private living space and a passive strategy of building envelope protection in overheated period. Their "ability" to protect from external environmental factors like sun, wind, rain and the amount of natural light inside the building depends on their configurations (horizontal and vertical limits) and on the materials that constitute them.

Although it is demonstrated that the presence of shaded spaces reduces the temperature fluctuation producing a more liveable environment (Chun et al., 2004), current comfort standards are not appropriate to evaluate well-being conditions in spaces that are neither interior nor exterior.

In this sense, it is necessary to assume a different approach to demonstrate their effectiveness. According to Potvin (2000), the presence of urban transitional spaces as porches provide a progressive adaptation of the body to a new environment. Even though this phenomenon cannot be clearly evauated, there are researches that deeply investigate the perceived thermal comfort related to the psychological effects (Nikolopoulou and Steemers, 2003). In transitional spaces, the adaptive behaviour of people is demonstrated by the positive feeling resulting from the experience of passing through gradual conditions between the interior and the exterior. Moreover, the vision of a shaded space that anticipates the coolness sensation is a form of thermal "gestalt" which defines the richness of sensations that associate the multisensory perception to the metabolic and behavioural mechanisms of thermal regulations.

Thus, not only the physical effect of shading, but also psychological aspects related to multisensory experience are important issues that induce social use of transitional spaces.

THE PORCH AS A TRADITIONAL CLIMATIC MODERATOR

This research focuses on a particular transitional space usually called "porch" in Mediterranean countries. It is a "perimeter type" that in another part of the world has different cultural or climatic values. In traditional Japanese house where it is named "engawa", it is a house extension that creates a continuum with the interior, while in tropical countries it has a stronger climatic impact and it is called "verandah" (Maragno, 2010).

In temperate countries, the porch is present both in its introvert and extrovert expression, along the streets and inside the courtyards. It has its origins in classical civilizations but its configuration has changed through the history to meet specific functional and aesthetic requirements.

The term "porch" derives from the Latin word "porticus" referring to a covered, columned space facing to a religious or civil building. On one side with a very symbolic value in relation to the concept of access to the sacred area of the temple, while in its public meaning with the name of "stoà" as place of philosophical, political and commercial meeting. In the private roman house the "peristyle" defined a certain internal realm around a courtyard. During medieval times it has been used in the monastic architecture inside cloisters as a space for meditation, than in the Renaissance it was a recurrent element in palaces courtyards or at upper floors named "loggia". In modern architecture, it appears in the form of modular balcony or delimited by Le Corbusier "pilotis". Today the porches are built with new technologies and materials often with bad results in terms of climatic control, as previously mentioned.

The morphology of a porch is defined trough spatial characteristics that are useful also to analyse other configurations of "perimeter spaces". These spatial characteristics are: the "degree of enclosure" (enclosed or attached) in the building volume, the "proportions" respect to the façade (punctual or linear) and the "level" at which is located (ground or upper floor).

According to these variables, the porch can be defined as "enclosed", positioned at the ground level and "linear" since normally its length is much more than the other dimensions.

The position on ground floor makes the porch a space with a strong link with the surrounding open space with a pontential high level of social interaction and, for this reason, the permeability of the open side (e.g. distance between columns if any, presence of shading elements etc.) acquires great importance. Then the characteristic of being “enclosed” means that the upper horizontal limit is not exposed to the solar radiation but it only makes shade. Finally, the fact that the porch is linear allows its analysis in section, considering only the depth and the height: if it has the proportions of a corridor, it is only a space of circulation while if it is wider it can become a place for static activities.

In the perspective of a new project or a renewal, each of these variables assumes the role of a design strategy with a functional, environmental and aesthetic impact.

Environmental potential

Especially in temperate latitudes, the porch has a great climatic importance because of its good response to the variability of the climate: it protects from direct sunlight in summer but allows sun penetration in winter.

From a thermal point of view it enlarges the perimeter “potentially passive zone” (Baker and Steemers 2000) of the building in which the climate can be moderated without mechanical control systems. In relation to natural light, the porch works as an “intermediate light space” which permits the entry of daylight in the adjacent building through wall openings. Thus if it is designed so as not to reduce too much the daylight availability, it can provide a decreased and less contrasting light level to the interior zones facing the porch.

The effectiveness of a porch in relation to thermal and visual comfort depends primarily on its geometrical configuration, the orientation and the materials that constitutes its limits.

The solar radiation is the most critical environmental factor because it needs a contradictory architectural response according to the season and to its direct and diffuse components. Preventing direct sunlight creating shadows means to reduce also the infrared re-emitted radiation. Diffuse radiation is reduced as well affecting the daylight levels inside. The reduction of direct sunlight has positive effects because it increases illuminance uniformity and reduces contrasts preventing glare. It also creates pleasant effects of “penumbra” but you have to be careful in order not to go below the threshold of visibility. It’s worth noting that the amount of daylight inside should be considered togheter with the wall openings size and position.

All these issues refer to the importance of integrating different (and sometimes contrasting) environmental aspects in the design process in order to balance the effects primarily in relation to the user needs.

METHODOLOGY TO EVALUATE THE ENVIRONMENTAL CONTROL OF A PORCH

Many works have contributed to the quantitative evaluation of daylighting and sunlight control with energy simulations but few researches have explored the combined visual and thermal aspects related to solar radiation. The aim of this work is to propose a methodology based on an integrated approach that takes into account the requirements of a shaded area with the need of daylighting inside the building. In this way, architects can be helped to solve the problem of associating aesthetic qualities to environmental issues and functional needs.

Evaluation process

In order to evaluate the environmental potential of a transitional space configured as a porch (as described before) it is important to individuate the main parameters which represent its behaviour at micro-urban level.

A configuration comprehends the building surfaces that define the limits of the porch and the urban surrounding space. It is defined in terms of latitude, orientation, proportions and materials. In a preliminary design stage, the geometric parameters are more important than the material’s effect. Later, to have a more detailed analysis, it is useful to introduce the physical properties of the materials. The key issue is to balance the requirement of shading with the need of opening to the sky. Thus the first step is to evaluate solar accessibility in different seasons. The influence of external obstructions is assessed in terms of "aspect ratio" (H/W, the height of the building to the width of the open space) during the winter solstice when the sun is lower in the sky and the direct radiation is desiderable. It is possibile to define the two opposite urban scenes in relation to the solar access: a street canyon completely shaded or a wide open space (as a square) without influence of obstructions.

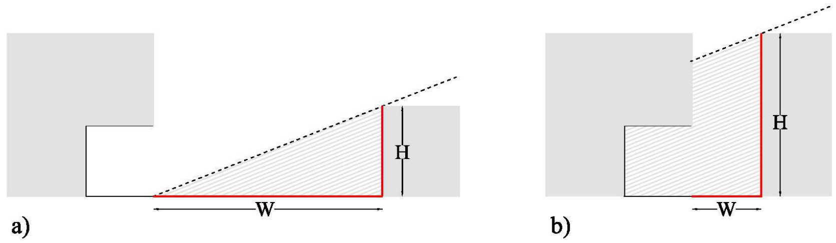

Figure 2. Solar accessibility in winter solstice at 45°N latitude in two urban contexts with the aspect ratio of a square (a) or of a street canyon (b)

On solar access and urban geometry, Oke observes that an "H/W of approximatively 0.6 seems to be a suitable upper limit to maintain solar access in a city at a latitude if 45°N" (Oke, 1988). The need of opening to the sky is not only related to the thermal aspect but also to the daylight issue. In previous studies (Littlefair, 2001) it is suggested a spacing angle for temperate climate, that is nearly 35°. In fact, a transitional space in a street canyon tend to lower the sky component of daylight but at the same time the reflective properties of materials could increase illuminance levels due to the diffuse light reflection within the canyon.

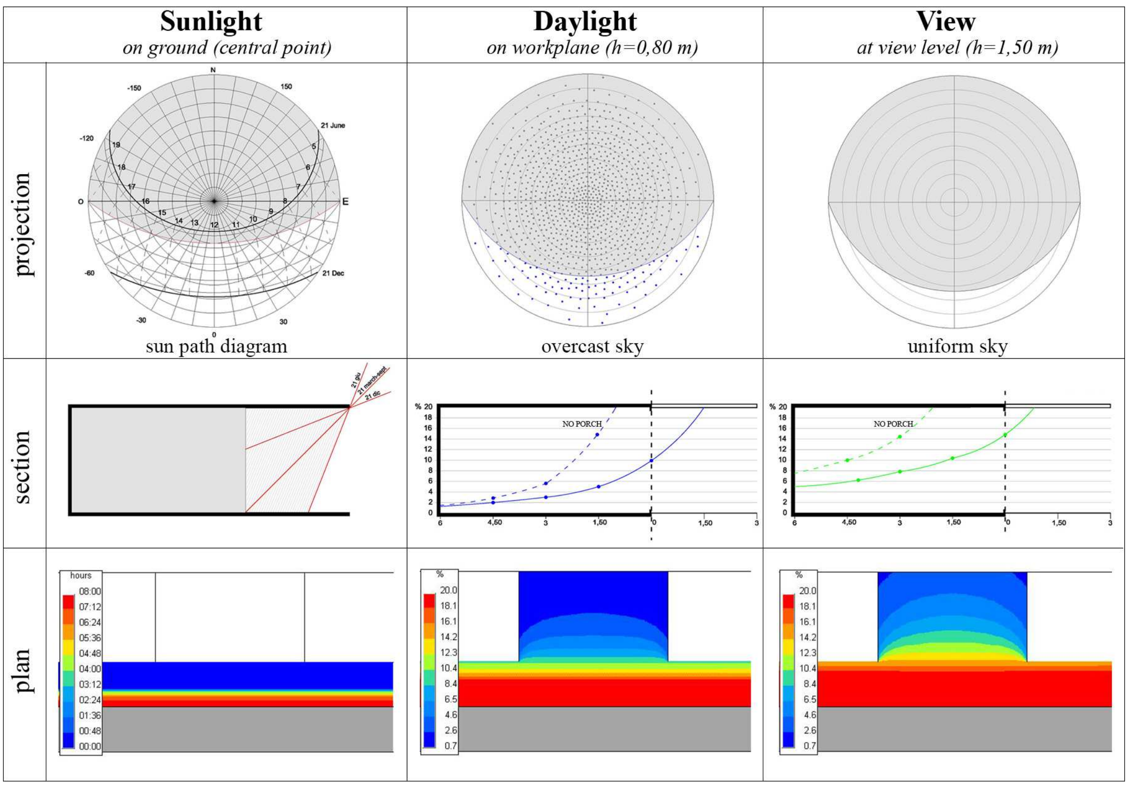

Figure 3. Evaluations and related representations. (e.g. H/D=1 and facade completely glazed)

After the context analysis, the evaluation should focuses on the geometrical effect of the porch defined in terms of aspect ratio H/D, since it is assumed of infinite length (Fig. 4). The prediction of the sunlight and daylight distribution in the transitional space and in the adjacent interior rooms can be performed using different procedures (e.g. algorithms, nomographs, prediction tools, scale model-measurements and simulation programmes).

A simple graphic way to assess the direct sunlight impact in a point consists in overlaying a sun path diagram of the selected latitude to an obstruction mask properly oriented in a plane projection of the sky vault. Thus, it is immediately visible if the point meets the requirement of being shadowed in summer and not in winter. The unobstructed part of the mask gives also information on visual comfort (changing the reference point height above the ground), evaluating two aspects. On one side, it provides directly the percentage of visible sky from that point as Sky Factor (SF) measured considering a uniform distribution of the sky vault. This parameter is related to the pleasant effect of having a visual link to the esterior and for this reason it is interesting to evaluate it at the eye level of a standing person (1,50 m). On the other side, overlaying a dot chart representing the illuminance distribution of an overcast sky (worst-case scenario) it is evaluated the Daylight Factor (DF, the ratio of interior horizontal illumination to exterior unobstructed horizontal illumination) as a first approximation. In fact, actually, the number of dots in the opening area represent the sky component of the DF, the illuminance received directly from the sky (neglecting in this first stage the reflected light from surrounding surfaces). In this way, for Mediterranean countries, sometimes the amount of natural light can be underestimated because in the southern latitudes there is a high frequency of clear sky conditions and that increases the contribution of radiation reflected from ground. In our case, considering the northern Mediterranean areas with temperate climate (latitude of about 45°N) it is reasonable to consider an overcast sky (in a first stage). Moreover, there are many design parameters, such as surfaces reflectances, window shape and size, and optical properties of the glazing that are unknown by the designer at the early design stages. For reference, a room that has a DF of less than 2% is considered poorly lit while rooms with DF between 2% and 5% are considered ideal for activities that commonly occur indoors.

Using different representation techniques, it is possible to have a more comprehensive description of the parameters values in the space. Especially at the early stages it is very useful for a designer to have simoultaneous views (plan, section etc.) of the same object (Fig. 3).

In this study the parameters described are calculated with the help of Heliodon 2 (Beckers, 2009), a simple simulation software that allows faster evaluations and multiple view of the same geometry. Other more sophisticated tools (e.g. Radiance) enable more precise assessments but they are much more complex to use and the computation takes longer time, thus they may be of help in a further step of the design process to verify the choiches made.

The study model

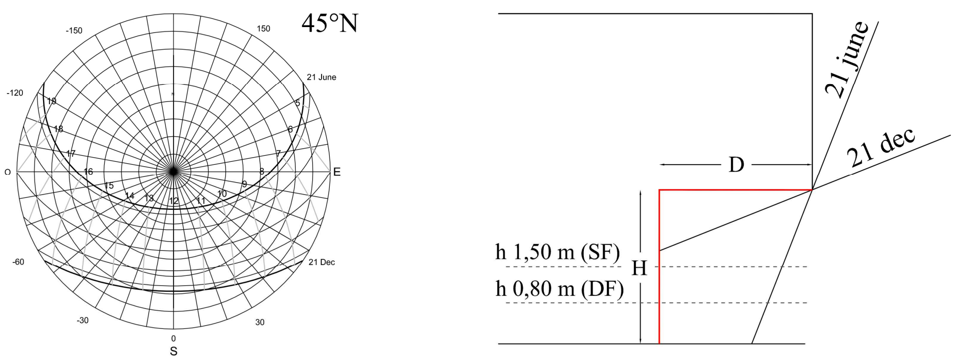

Figure 4. Configuration of the study model.

The effect of proportions and orientation of the porch on the luminous and thermal performaces is evaluated through a study model (Fig. 4) considered representative of possible real cases. The model is located at a 45°N latitude, in an urban context in which external obstructions does not affect solar accessibility (Fig. 2, case a).

It is tested in different hours of the day and in the two seasons with conflicting requirements (summer and winter). The proportions tested are based on the observation of different existing porches and ranges from 0,5 to 2 H/D.

The evaluations are performed using indexes that allow comparisons among different configurations. The percentage of shaded area in summer is evaluated on the ground surface (on the 21st of June at noon) as Shading Factor, while the ratio of sunlite area in winter winter (on the 21st of December at noon) is assessed on the building wall as Sun Factor. The Daylight Factor (actually its sky component as previously explained) is evaluated at a work plane height (0,80 m) while the Sky Factor at the eye level of a standing person (1,50 m).

The building wall is the critical limit on which to evaluate the porch and the effect on the interior space depends on the porch's geometry and the wall configuration, in particular in terms of both windows size and position in the wall.

Results

Regarding the porch orientation: the more the angle deviates from the east-west axis the more the porch becomes useless for all tested proportions. If the porch is very deep (H/D < 0,5) there is a lack of daylight inside and at least 50% loss of solar gains in winter. This first observation highlights the importance of integrating different aspects in the evaluation process.

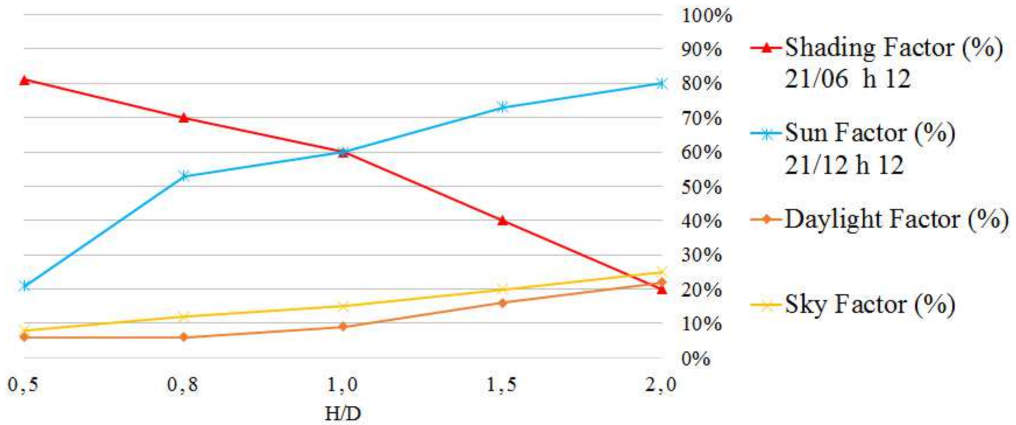

Figure 5. Effect of different aspect ratio on thermal and visual parameters.

Fig. 5 shows the comparison between different aspects ratio integrating the thermal and luminous aspect. Therefore, DF and SF are considered as punctual values on the building façade, the physical boundary that separates the inside to the outside.

Observing the graph, it seems that the aspect ratio of 1 offers the best balance between protection and openness to the sky, with the same percentage of shaded ground in summer and wall exposure to solar gains in winter, with a medium value of daylight and view factor on the building envelope. On the contrary, the extreme cases show that: if the deptht is double than the height the only benefit is to have a wide shaded space in summer, while if the porch is too narrow it does not provide a usable space and it is only a solar protection for the building envelope. Of course, as it mentioned before, these analysis do not pretend to give accurate results but they are first evaluations to be integrated with other design features.

CONCLUSION AND FUTURE DEVELOPMENTS

The partial findings presented in this paper are part of a wider research that investigates transitional spaces in relation to human well being with the aim of providing guidelines for an architect in the early design stages. In particular, the importance of the porch as a climatic moderator in temperate Mediterranean latitudes has been clarified. Since environmental potential is well exploited only if it anticipates the human expectations, the method presented makes the effort to integrate different and sometimes contrasting needs especially in terms of daylight and sunlight.

Further evaluations can be performed taking in account other design features. In particular, the material effect is to be investigated: on one side in terms of exterior finishing, taking in account the surfaces' multi-reflectances for a more precise assessment of the illuminace levels and eventually the occurance of glare; on the other side the thermal effect due to riemission of long-wave radiation.

All the design choices modify the building exterior appearance with consequent effects on multisensory perception and on the integration within the surrounding context, especially in the case of building renewal or in an extremely dense urban context. Resolving all of these questions is a complex issue; therefore, the priorities of a project should be defined in relation to the specific user needs and balanced with the external costraints in order to reach a satisfactory compromise.

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The Cross Socio-cultural and Climatic Adaptation Aspects of the Peranakan Chinese House in Kelantan

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ABSTRACT

This study unveils PCK house by revealing its sustainable architectural features in both cross-cultural and climatic adaptation aspects. The Kelantan Peranakan Chinese (KPC) are a group of Chinese-Malay-Siamese mixed-race community living in the state of Kelantan, Malaysia bordered with south Thailand, a Malay-Muslim majority region. The KPC's ancestors were Chinese from Min Nan, the southern Fujian province who migrated to and settled down in Kelantan in the last 300 years. Throughout these periods, KPC have socio-culturally assimilated into Malay-Thai native identity and adapted into the local tropical environment. One of the most noticeable features of these cross-cultural and cross-regional climatic adjustments is their unique domestic architecture. Ritually, the layout of a KPC house strictly inherits the basic Chinese domestic house planning, where the ancestral hall is positioned in the central and both sides of the hall are bedrooms. Externally, the style of the KPC house resembles typical Malay-Thai timber stilt houses. These amalgamations are required in order for KPC to fulfill their spiritual needs, and at the same time to harmoniously sustain in a new socio-cultural and nature environment. This study unveils the KPC's creativity in modifying the architecture of their domestic house by regulating certain socio-cultural and ritual-religious variables to suit local climate and contexts. The purpose is, certainly, towards creating a more socially and environmentally sustainable residence. The methodology of this study is based on contents analyses of five measured drawings and observations on more than 400 visited houses. Simple temperature, humidity and illuminance measurements have been taken to provide some quantifiable figures. These analyses suggest that in adapting into a new local context, KPC are more concerned on how to achieve and maintain their ritual needs and identity over climatic aspects.

INTRODUCTION

In the quest of energy conservation and visioning the low carbon developments, investigation on how vernacular houses sustain naturally by their passive energy mechanism is getting more attention in environmental science researches recent years. Undeniably, vernacular architecture has been highly cited by scholars as one of the established archetypes evolving over the time through the processes of intertwining and adapting nature and socio-cultural aspects. The purpose is to achieve a balance living condition for humans to sustain harmoniously in their domestic sphere and surrounding contexts.

Vernacular house is the metaphor of these nature and socio-cultural symbiosis reflecting on its house form, spatial layout, site planning, material selection, etc. In searching for the lessons of sustainability aspects of vernacular architecture, however, most researchers focus on quantifiable climatic aspects than human or socio-cultural aspects. Albeit climatic architecture features are important supportive mechanisms to help providing climatically comfortable living to the residents, it is not always the main choice for vernacular houses where socio-cultural contexts, inherited rituals and identity aspects may play decisive factors over the climatic aspects.

So far, most environmental researches on vernacular architecture focus on homogeneous setting. The outcomes might not offer diverse and alternative lessons which are very useful in hypothesising the way of sustaining the growing plural and cross-cultural living environment in today's world. Hybrid vernacular architecture, or fusion of two or more cultures, perhaps is one of the best subjects to be examined. KPC's vernacular architecture offers great research exploration on how cross-cultural and cross-regional climatic adaptations could happen, particularly when involving different socio-cultural and environmental contexts; for example adapting sub-tropical climate into tropical climate or from a Min Nan Chinese culture into Muslim-majority context. The study shows the KPC are adaptable to their external architecture identity by adapting local influences in materials, design elements, and styles in order to sustain ecologically in the new environment. However, these amalgamations do not prevent their strong instinct to inherit their Chinese cultural identity, ritual and spiritual needs by remaining the Chinese architectural principal in spatial organizations in their house layouts by scarifying some climatic quality aspects.

The methodology of this study is based on contents analyses and observations on five measured drawings from KALAM (Center for the Study of Built Environment in the Malay World), UTM, and more than 400 identified houses from five fieldworks. In the aspects of climatic adaptations and socio-cultural assimilations, analyses are made from the comparisons between KPC houses and their vernacular houses in Min Nan, China as well as Malay houses in Kelantan. In the aspect of climatic adaptations, aspect of ventilation, lighting, materials, etc. are discussed and supported by some simple quantifiable measurements. Socio-cultural amalgamations such as factors which influence the adaptations and changes in KPC architecture were gathered through observations, interviews and literature reviews.

GEOGRAPHY AND CLIMATE

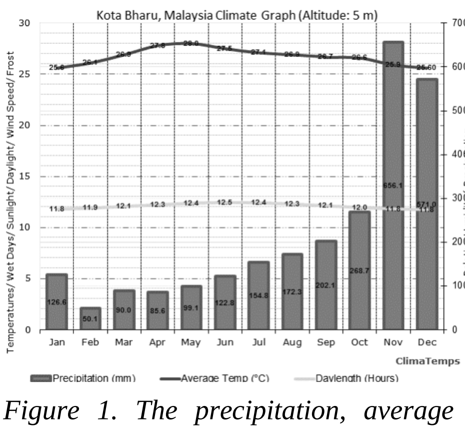


Figure 1. The precipitation, average temperature and daylength in Kota Bharu. Source: http://www.malaysia.climatemps.com/.

The Peninsula Malaysia, strategically located between West and East Asia, has been an important melting pot of commercial and cultural exchange since six hundred years ago. Today the diverse multi-racial demographic, comprising 60% Malays, 27% Chinese, 10% Indians and others, in the Peninsula is the result of these historical consequences. Kelantan, the most north-eastern state of Malay Peninsula, shares its border with Southern Thailand. Covering the area of 15,099 km2, Kelantan is the sixth biggest state in Malaysia. With a population of 1.5million, the density of the state is about 100 where the concentration of population can be found in Kelantan Plain, a fertile agriculture plain dominated by the main river system, Kelantan River, and other smaller river systems.

Generally, the climate of Malaysia is tropical rainforest, having hot and humid ambience and no distinct rain and dry seasons year round. With the latitude and longitude slightly north from the equator 5.2500 ° N, 102.0000 ° E, Kelantan has clearer dry and wet seasons compared to southern part of Peninsula Malaysia. The wettest period is from end of October to early January when the Northeast Monsoon brings heavy rain to the state, whereas the driest period is from February to May. The average yearly rainfall and temperature in Kota Bharu, the state capital, is about 2600mm and 26.7 ℃.

HISTORY

Figure 2. The former Pattani Region. Kelantan (no.8) shares border with southern Thailand.

Facing the South China Sea, the Northeast Monsoon does not only bring heavy downpours to Kelantan, but historically it had been shipping the Chinese immigrants to the east coast of Peninsula Malaysia. The coming of the Chinese into the Southeast Asia can be traced back to 3rd century A.D. There are very rare academic records on the history of the Kelantan Chinese in the early period, but the existence of a 300-year old Chinese temple at Kampung Tok' kong proves that a small group of Chinese had already established their community in Kelantan in 18th century.

The early Chinese immigrants who landed in Kelantan were mainly from Min Nan, Fujian province, China. Most of them settled down in rural areas along Kelantan rivers' basins to find livelihood. Their comings were much earlier and small in numbers compared to those Chinese immigrants who migrated massively into the British Malaya in 19th to 20th century. Due to separation by the central mountain range and limited infrastructures, social contacts and economic exchanges between Kelantan Chinese and Chinese from other Malayan states have been scant. Having long been away and disconnected from their Chinese roots has resulted in that the Kelantan Chinese gradually assimilated to the natives' way of life by acquiring local Malay language as their mother tongue, adapting to local food, costume and others. One of the most obvious assimilated features is their fusion domestic house which shows interesting cross-cultural and cross-regional climatic adaptations. This community is widely known as *Cina Kampung* or village Chinese by the local Malay and Siamese natives, but the community prefer to be called as Kelantan Peranakan Chinese (KPC), means local born Chinese or the Peranakan in short.

KELANTAN PERANAKAN CHINESE VILLAGES AND STILT HOUSES

Figure 3 Location of KPC villages. Most of the villages are located along the river basins of Sungai Kelantan and other smaller river systems.

Almost all KPC villages can be found along the fertile river basins of Kelantan, Pengkalan Datu and Kemasin rivers. Alike native Malay and Siamese traditional villages, their houses are usually located near to the source of their livelihoods such as paddy fields and rivers (Chen, 1998). River fish provides important source of protein to the KPC. Besides, rivers were the main highway for the KPC to communicate from one village to another and ferry their livestock, goods and crops to towns for trades. Although the rivers have not been actively used as in former days, the rivers are an important symbol of how the community sustained their living in the new environment. This could be deduced from the practical way on how most of the KPC orientated their houses facing the rivers, significant to their source of livelihood, economy, transport and communication. Traditionally, the orientation of Chinese house is facing south (坐北朝南) following the Chinese geomancy principals, while to climatically avoid cold northern winds during the winter months. Nevertheless, extreme weather is not part of issues in the hot-humid climate of Kelantan and the principal of orientating the house facing south is impractical for KPC to conduct their daily activities with rivers.

Most KPC houses are sparsely located from each other on linear grid pattern by facing rivers or roads. The KPC village pattern is obviously disparate from Min Nan traditional village pattern, as Min

Nan villages are arranged in cluster group patterns. Two reasons could be hypothesized; least concern of security and climate in Kelantan. In Min Nan, traditional houses are closely grouped together to form a big cluster. The purpose is to create a strong surveillance network to defend the villages from bandit attacks. Secondly is to keep the villages warm during colder months. Since security is not part of the concerns in Kelantan, KPC houses are not densely planned or arranged in cluster manner, which allows greater wind velocity and penetrations to help discharge contained humidity. Besides, the practice of opening new lands after the existing villages have reached certain levels help to maintain the villages in low density, which is critical to help KPC village to sustain its micro-climatic aspects. To maintain the social networking and kinships, normally the new villages are opened opposite the rivers or adjacent to the existing villages. Therefore, many KPC villages can be found located side by side or facing each other along the rivers in Kelantan. Due to small number of population, KPC villages' public facilities such as schools, markets, public spaces, etc. are shared with surrounding Malay and Siamese native villages. Sharing these facilities enhances the interactions between the natives and the KPC, which it is very important for the KPC to mutually and socio-culturally sustain as a minority in the natives' socio-cultural landscape.

THE HOUSE UNIT

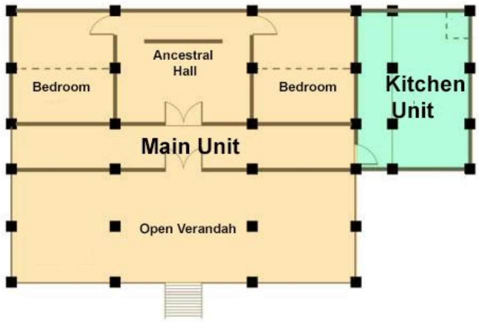
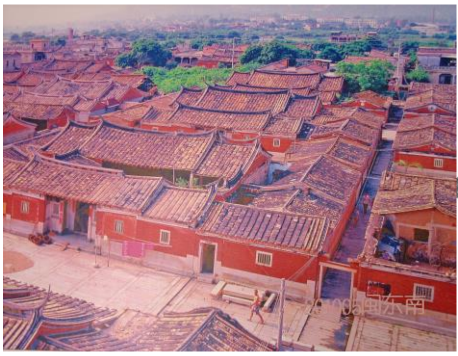


Figure 4 (left) The KPC house plan comprises two units: main unit and kitchen unit. Figure 5 (right) shows the façade of KPC house with large curvy roof to help discharge rain water and reduce the velocity of strong wind.

Basically, a KPC house consists of two units, which are the main house (unit) and kitchen house (unit). The main unit has an ancestral hall and bedrooms. The kitchen unit is where kitchen, dining area and bathroom are located. Similarly to a Malay house, a KPC house also comprises of *rumah ibu* (main house) *and rumah dapur* (kitchen unit). In Min Nan, China, the house unit can be repeated and expanded to form a big enclosed complex to accommodate bigger family members of few generations. From climatic point of view, the enclosed complex is not suitable in hot-humid climate where accumulating humid and high air temperature will make residents feel uncomfortable. In Malay village, extended families normally will establish their own houses adjacent to or in the nearby areas to their parent houses. Several Malay houses form a family cluster and several family clusters form a Malay village. This trend also applies to the KPC house where a village normally comprises of several family clusters. Besides, the reason why the KPC and Malay houses are small may be due to the limited spans of timber material. Most of KPC house structure is about 9 x 6 m (main unit). Technically, it might be difficult for timber structure to hold a large span without established construction skills. Another interesting sustainable feature of Malay and KPC houses is these houses can be dismantled and reinstalled from one location to another location.

The House

Western scholar Kohl (1984), who studied on the development of Chinese architecture in West Malaysia and Singapore, observed that the Chinese community is pretty practical in dealing with their domestic houses, signifying that "*satisfied with their fitness of purpose, serviceability and aesthetics, the Chinese have not altered their architecture forms, with architecture becoming more a rule of thumb than 'art'* *after the Tang dynasty*." Even the Chinese immigrants who have settled down in foreign lands for few hundred years would stick with the basic house plans. This is suggested by Chua (1997), stating that the principal of Chinese house is *"not only cut across time, but also 'survived transplantation' from its origin to a new environment."* This principle has been reflected in KPC house.



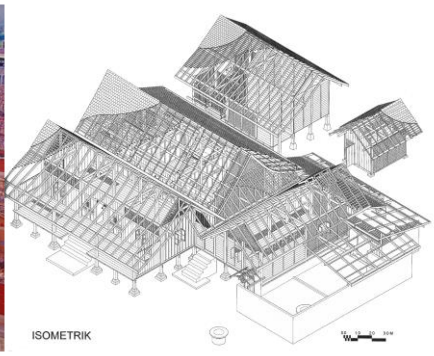


Figure 6 (left) Min Nan house can be repeated and expanded to allocate few generations of family members Figure 7 (right) KPC house can be expanded,or dismantled and relocated to other locations.

The KPC house basically can be divided into three parts: the body, lower floor, and roof. The body is the main house where rooms are located. The lower floor is the area below the elevated timber floor of the main house. The roof is the upper level of the main house. This configuration provides a natural mechanism for KPC house to adapt into its environment.

The Body

As mentioned above, in term of spatial arrangement, Chinese domestic houses are rarely seen having much of regional differences. The internal layout of the Chinese house strictly follows the Chinese architectural concept of "one bright, two darks." (一明两暗). The bright zone is where the ancestral hall is located in the middle of the house facing the main door. The dark zones are the bedrooms located at both left and right sides of the ancestral hall.

Figure 8 (left) Inside the main door is the private domain, where the ancestral hall is located. Figure 9 (center) Ancestral hall is rarely opened to visitors, therefore there are considerations in its ventilation and lighting design, as sacredness and privacy are more important than environmental aspects. Figure 10 (right) KPC have assimilated to native behavior by utilizing the elevated timber floors in their daily activities. KPC have got rid the culture of using furniture. Source: Berita Harian, 4 April 2011.

To achieve brightness in the ancestral hall, two small windows can be found at two sides of the main door of the ancestral hall. Above the main door are timber lattices to allow further penetration of light and air into the hall. Sometimes, small openings covered by transparent glasses can be found on the roof over the ancestral hall to enhance the brightness of the hall. According to the Chinese architectural principal, the dark zones are the bedrooms located at both left and right sides of the ancestral hall. Normally in the bedroom, no window is placed on the wall facing the front part of the house. Only a small window can be found at the side wall of each bedroom. Therefore, the bedrooms are darker than the ancestral hall. Usually, native Malay and KPC houses have low lighting ambience in indoor spaces. According to the simple indoor lighting measurements on a KPC house (refer Graph 1), most of the internal rooms hardly receive 100 lux. However, it creates a more relaxing indoor atmosphere for occupants to rest since most of the daily works are conducted outside of the house or in the kitchen. However, the method of using smaller windows is not due to native influences but the KPC's intention to maintain the origin identity of the Min Nan architecture. The purpose of smaller windows in Min Nan house functions for security reasons and minimizes the effect of northern cold wind. Nevertheless, the atmosphere of Min Nan house is much brighter than KPC house because there is a big central courtyard in the enclosed compound of Min Nan house. In KPC house, in the quest of achieving its ritual needs and architectural identity, the spatial arrangement of “one bright, two darks” with minimum opening makes the indoor lighting extremely low. The long and large overhung roof at veranda further reduces the light penetration into the house. This situation is worsened by the main door and windows of the ancestral hall being closed in the most of the time. The rational of this incomprehensible practice perhaps is due to the feeling of insecurity and sensitivity being in the majority Muslim social setting. As Teo (2003) suggested, the attitude of the KPC is vividly reflected in their way of life where they practice native behaviour (local costume, culinary, sociolinguistic, etc.) in the frontage, while keeping their own Chinese religion and ritual in the backstage, which are usually contained in their own houses and domestic spheres. It shows that maintaining good ethnic relationships and sustaining a mutual-respect living environment with the local natives are given the priority by the KPC and the external factors such as climate and thermal comforts are relegated as secondary aspects.

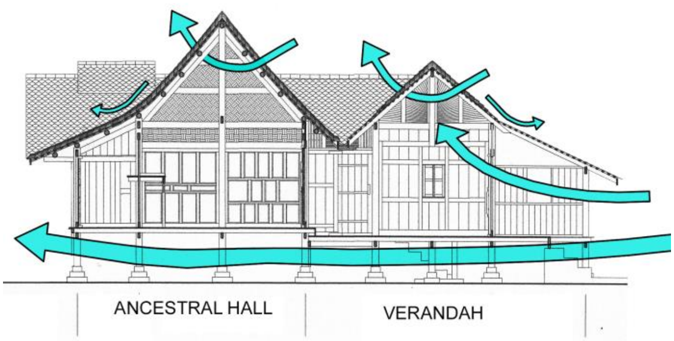
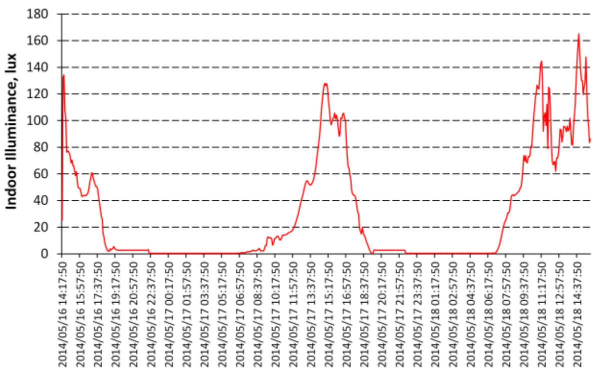
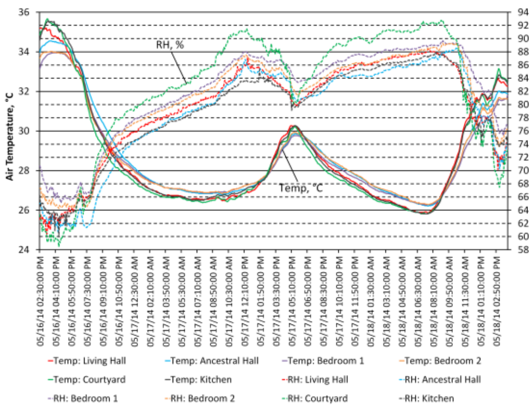


Figure 11 Cross ventilation helps to reduce humidity. Source: KALAM, UTM.

Indoor ventilation and lighting are interrelated. Both are determined by the size and position of openings. Cross ventilation, particularly at body level, is critically important to achieve thermal comfort in hot-humid climates. The airflow will evaporate heat from the human skin allowing the occupants to feel cooler (Lim, 1987). In a Malay house, even though the indoor spaces are considered private to family members, usually windows and doors are open widely to allow natural ventilation occur. Furthermore, the concept of open plan where there is less or no partition is used to divide indoor spaces allows greater cross ventilation to happen in Malay house. In contrast, the concept of indoor space in KPC house is obviously more private, perhaps sacred, than that of Malay house. As mentioned previously, the main door and windows of the ancestral hall are remained closed to prevent direct contact of passer-by to the ancestral hall. Besides, the internal spaces, bedrooms and the ancestral hall are divided by walls which will definitely slow down or block the wind entering the house. However, the problem of limited body level ventilation in the indoor spaces is reduced by roof level ventilation. The steep pitch roofs provide higher roof attics which allow accumulated indoor hot temperature release at the roof level and keep the lower part of rooms cooler. However, this is not sufficient to reduce the indoor air temperature to comfort level.





Graph 1 (left) and 2(right): Sample air temperature and daylight measurements taken from a KPC house (Chan Awang's house, Kampung Sering). The house has an extended living room in front of the ancestral hall. The thermal comfort temperature ranged from 23.5 - 28.5 deg C with neutral temperature (feel neither cold nor hot) = 26 deg C. Generally, all the spaces yielded temperature higher than the comfort zone starting from 11.00am to 11.30pm (except day 2, it was a raining day). For daylight, the living hall only yielded > 100 lux during 1030am to 330pm on the 1st and 3rd day (except second day).

Although the indoor air temperature and lighting are poor, KPC rarely use indoor spaces at daytime. KPC men preferred spending their daytime and doing domestic tasks in the open veranda, while women and children spend most of their time in the dining area and kitchen where Ratio Humidity (RH%) and air temperature are relatively lower due to better openings. Guests are usually entertained in the open veranda area, and the indoor spaces are only generally being used at night when the air temperature and RH% decrease to the comfort level. The roof level's fenestrations and the thin clay roof tiles easily release hot heat, making the indoor area comfortable to relax at night. This suggests that in maintaining the ancestral ritual and identity, KPC choose not to change their spatial layouts and opening for better lighting and indoor temperature but choose to change their living behaviour by assimilating native's way of life and alter its domestic architecture.

The Lower Floor and Roof

Figure 12 Plaited bamboo walls are used to discharge hot air. Figure 13 shows the deep roof which helps to reduce the glare and provide more shade to the house.

Either on lower plains or higher ground, KPC houses are usually elevated on timber stilts, like those of Malay, Siamese and many Southeast Asian traditional houses. Formerly, the underneath of elevated floor was used for storage and to rear domestic livestock. This space allows for a buffer zone between elevated timber floor and the ground. This gap prevents the humidity and moistures from the ground sip into timber and damage its strength and make the residents feel uncomfortable when touching or sitting on it. The elevated floors are very important for the KPC, since most of their daily household activities such as eating, sitting, relaxing, and sleeping are conducted on the elevated timber floors. This shows that KPC has changed their Chinese way of life from using furniture to sitting on the floor as Malay native. From the climatic aspects, the higher the house is elevated, the greater wind velocity can penetrate into the house. This helps to reduce the KPC house's RH level.

Once, the roof of KPC house was made from thatch. Since 1960s, the roofs have been covered by a type of clay roof called *atap Singgora*, imported from Songkhla, Thailand (Winzeler. 1985). The roof is pretty thin and easily broken but it looks closer to the roof tiles in Min Nan house. Like those of Kelantan Malay house, the roof tiles are loosely hanged on the batten to allow breeze to slip inside the house, compared to Min Nan houses whose roof tiles are cemented onto each other to prevent blowing up by typhoons. The curvy tapering roof form is the most expressive part of the KPC house. It symbolizes the Chinese Min Nan architecture identity and their origin. The typical Min Nan house's roof curves into two directions – the ridge and hip rafter, making the roof having greater velocity to discharge water and redirect wind; particularly during the typhoon seasons. In response to higher precipitation average 2600mm in Kelantan, the KPC design the roof steeper in the angle at about 45 degrees. The purpose is to discharge the rain water more smoothly, particularly during the heavy downpour in monsoon seasons from November to January. The pitch of the Min Nan house roof is at about 30 degrees, making the depth of roof lower than that of KPC house. With shallower roof depth, Min Nan house is able to allow greater daylight penetrating into the building and to make the building interiorly and exteriorly brighter. In contrast, the KPC house has steeper pitch and longer roof overhang to shade excessive sunshine. Therefore, the proportion of the roof is much greater than the body of the house, which provides deeper shades to the open veranda. It also helps to reduce excessive glare. The effect of glare provides some security protection to the house owners, particularly in sunny days where one at the veranda can easily recognise any passer-by, but the passer-by having difficulty to figure out whether anyone is inside the house due to glare effect.

CONCLUSION

Having been migrated from sub-tropical region of south China into the tropical region of Malaysia, KPC have to judge what aspects that they can retain and what aspects they should adjust, accept and change in order to sustain environmentally and socio-culturally with the new native environment. These negotiations are illustrated in their domestic house design. Most obviously, KPC ancestors had chosen to follow the local Malay and Siamese natives in using local natural material to build their homes. The lightweight natural material with low thermal capacity such as wood and bamboo provide the house better thermal comfort in tropical climate, besides being visually and contextually harmoniously with the native villages' surrounding environment. To get rid the problem of contained humidity in tropical climate, KPC houses are kept in small units, with the houses being sparsely arranged and the floors are elevated. The purpose is to allow better wind velocity to penetrate into the house compounds and units for reducing the level of humidity. This illustrates that KPC have no longer follow their ancestor's norm of expanding their houses into a big complex to accommodate generations of family members, which it is not suitable in tropical climate where humidity will be difficult to be discharged. Besides, KPC has got rid their Chinese ancestor's furniture culture by adapting Malay natives' way of life by utilizing elevated timber floor as a living platform to conduct their daily activities. Judging from the KPC house's stilt house architecture, the KPC seem to have adapted into Southeast Asia native architecture tradition and further dissociated with their ancestral traditional house typology in Min Nan, China, where most of the houses are made from masonry and placed on stone platforms (Else Glahn, 1982).

However, the domestic sphere of KPC house is still ruled by the concept of Chinese ritual. Descending from Chinese origin, the practice of ancestral veneration is one of their cultural pillars which have to be performed in the ancestral hall. At two sides of the ancestral hall, the norm of placing male's bedroom at the left side and female's bedroom at the right of ancestral hall has further determined the concept of spatial planning inherited from their Chinese origin. Due to sensitivity to the Muslim-majority communities, the main door of the house where ancestral hall is located is always in closed condition. The smaller-size windows further restricts the penetration of light and air into the buildings, making the level of luminance low and air temperature hardly achieve comfortable level. To solve the problem, KPC have adjusted the use of these spaces. To avoid uncomfortable air temperature and low luminance level, these interior spaces are rarely used during the daytime but only at night when both aspects achieve comfortable levels. To substitute the interior spaces, KPC houses, like native houses, have wide veranda for men to rest and do their daily tasks during the daytime and women and children do their activities in kitchen unit where dining and extended family rooms are located.

These architectural adjustments are needed in order for them to fulfill their daily activities and spiritual needs and at the same time to harmoniously sustain in a new socio-cultural and natural environments. The KPC architecture reveals how certain socio-cultural and ritual-religious variables could be adjusted architecturally towards creating a more socially and environmentally sustainable habitat.

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Traditional Sustainability: Environmental Designs in the Traditional Buildings of the Middle East

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Traditional, architecture, sustainable, environmental strategies, comfort.

ABSTRACT

The traditional mud buildings present throughout the hot dry countries of the Middle East provide excellent references to the sustainable elements of architecture. This paper presents the results of the research of a few buildings in Saudi Arabia, Qatar, Bahrain and United Arab Emirates in terms of architectural problems due to climate, and the environmental elements as their solutions. The buildings studied ranges from mud houses, mud palaces to souks or bazars. These are, Shaikh Issa House in Muharraq, Kingdom of Bahrain, Al-Mulla House in Al-Ahsa, Saudi Arabia (K.S.A), Souk Waqif in Doha, Qatar, and Shaikh Saeed Al Maktoum House in Dubai, United Arab Emirates (U.A.E). Measurements were taken of air temperature, relative humidity, and airflow. Observations were made on the various aspects such as plan, form, orientation, sections, elevations, materials and methods of construction and details of the buildings. Comfort survey was conducted among the occupants. The paper shows that the traditional architectural solutions to the climatic problems of the Middle Eastern countries such as thick walls, small openings, shaded courtyards, use of local materials and a few special strategies work very well in the context in terms of providing comfortable environment indoors. The measurements of temperature, relative humidity and airflow compared to the comfort ranges of the region, reinforce the sustainable design of these buildings.

INTRODUCTION

The case studies for this research are located in Kingdom of Saudi Arabia, Kingdom of Bahrain, United Arab Emirates and Qatar, all of which fall under the broader umbrella of tropical hot-dry climate Ragette, 2012). The buildings range from market or *Souk*, small single courtyard house, to large multiple courtyard houses. The masons used local materials and methods in these buildings. An in-depth pilot research on the environmental behavior and related climate modifying elements and strategies of these buildings were conducted recently. These traditional building in the Middle Eastern hot-dry tropical climate is of mud. Whether made of poured in mud, or sun-dried mud blocks, they are good in making indoors cooler than outside (Bekleyen & Dalkiliç, 2011). The thicknesses of the earth walls help keep the indoors considerably cool (Vincent, 2008). With walls of high thermal mass and other environmental strategies, these buildings are able to keep the interiors much cooler than outdoors. Courtyards in these buildings meet environmental and privacy requirement well (Laffah, 2006)(Awadhi & Hasan, 2011).

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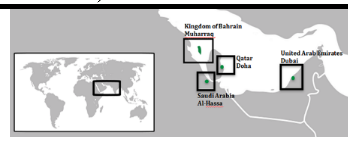
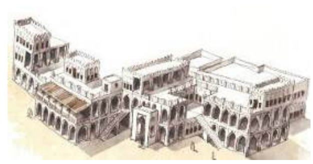
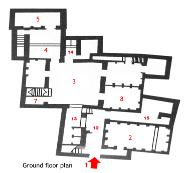
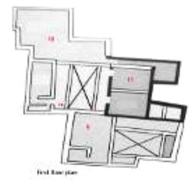
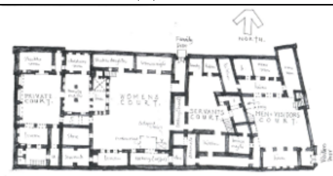
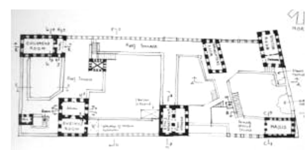
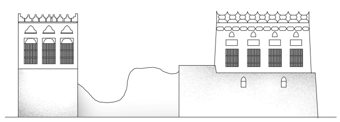
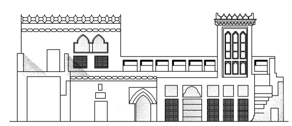
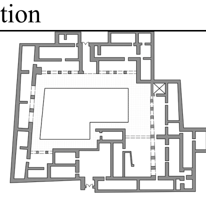
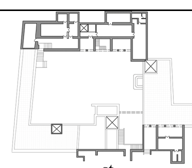
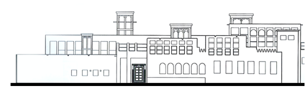
CASE STUDIES

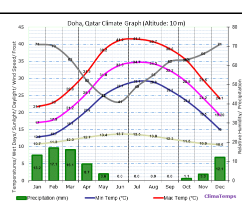
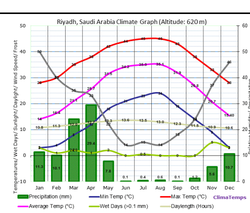
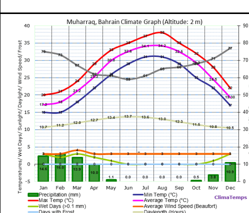
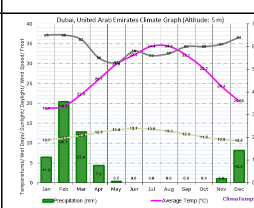
Location, Plan, Section, and Elevation

Table 1. Plan, Section and Elevation

Locations Map	 (1)		
Doha, Qatar Souk Waqif	 (2) Elevation	 (3) 3D view	 (4) Site plan
Al-Ahsa, K.S.A. Al-Mulla House	 (5) Main façade	 (6) Gr. floor	 (7) 1st floor
Muharraq, Bahrain Shaikh Issa House	 (8) Main façade	 (10) Gr. floor	 (11) 1st floor
	 (9) Elevation	 (12) Section	
Dubai, U.A.E. Al Maktoum House	 (13) Southern façade	 (14) Gr.floor	 (15) 1st floor
	 (16) Elevation		

Location, Climate and Building Description

Table 2. Location, Climate, Building and View

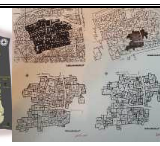
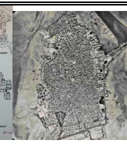
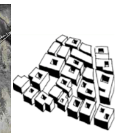
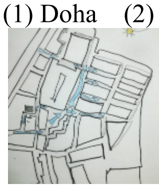
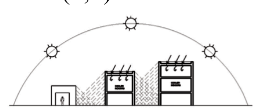
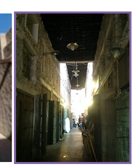
Location	Doha, Qatar 25.2867°N Coastal city.	Al-Ahsa, K.S.A. 25.4294° N Oasis city in desert.	Muharraq, Bahrain 26.2500° N Coastal city.	Dubai, U.A.E. 24.4667° N Coastal city.
Climate	 (1) Hot-dry tropical.	 (2) Hot-dry tropical.	 (3) Hot-dry tropical.	 (4) Hot-dry tropical.

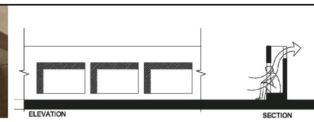
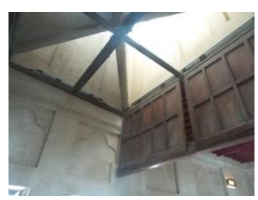
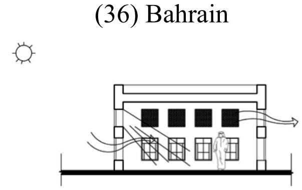
Building	Market complex. Narrow shaded roads, with wind tower-buildings.	Irregular shaped 3-courtyard building.	2 storied house with 4 courtyards & wind tower.	2 storied courtyard house with wind tower and *liwans*.
View	 (5) Wind tower house, Doha	 (6) Central courtyard, Al-Ahsa	 (7) Central courtyard, Muharraq	 (8) Central courtyard, Dubai.

FINDINGS: CLIMATE MODIFYING ELEMENTS/STRATEGIES

The Findings of the research is given in the following chart for ease of comparison of the architecture of the four countries. This also shows the environmental strategies, which are common in some of the buildings, as well as strategies that are unique to a single building.

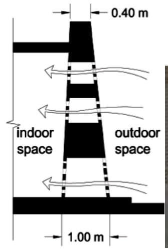
Table 3. Environmental Strategies

Environmental Elements / Strategies	Countries
Compactness Compact urban form, building shading building, shaded walkways. Protection from direct solar radiation & hot wind (fig 1, 2, 3, 4).	    (1) Doha (2) S Arabia (3) Bahrain (4) Dubai
Orientation Building oriented N-S for min. solar radiation and max. exposure to wind & cross ventilation (fig 5). Evaporative cooling from creek (fig 6, 7). Openings in north façade. Tilted east façade for northeast breeze (fig 8, 9).	   (5) Doha (6,7) Dubai   (8,9) Bahrain
Walkways/Alleys Double & triple height buildings, narrow roads, various angles of winding roads, building orientation create shade in the alleys (fig 10).	 (10) Doha
Plantation The photosynthesis strategy of plants reduces the heat gain on the roads, which reduces the temperature of immediate microclimate (fig 11, 12).	
Shaded Walkways/Alleys The alleys in many cases are covered with fabric to provide shade, thereby cooler alleys (Al-Eidi, L., 2013) (fig 14).	    (11,12) Dubai (13) Dubai (14) Doha
Façade Solid walls & minimum openings on the western and southern façades to delay & reduce solar gain (fig 15). **Windows** Small recessed windows & clerestory, few in number, bring controlled & indirect natural light, thus less heat gain. Wooden frame and shutters (fig 16,17)	   (15) Dubai (16) Dubai (17) S Arabia

Parapet Detailing Roof parapet consists of hidden openings which allow air movement and privacy (fig 18,19,20)	   (18, 19, 20) Bahrain
Courtyards Courtyards, generally small & partially shaded most of the time, help air cool down before entering indoors (fig 21, 22). Wells in courtyard help evaporative cooling (fig 23).	   (21) S Arabia (22) Dubai (23) Bahrain
Space Layering Space sequence is from outdoors to wide shaded corridor or *liwan*, then to room. Layering of space makes rooms cooler than outdoors. Breeze gets cooler by passing through this shaded space, before entering the room (fig 24, 25).	  (24, 25) S Arabia
Corridor/Arcade or *Liwans* Courtyards have surrounding arcades or *liwans*. These shaded semi-outdoor spaces block direct sunlight from penetrating indoors and provide shade to rooms; provide passage for occupants without being exposed to direct sun (fig 26, 27). Covered *liwan*, used for sitting, with thick roof and arcaded walls is cooler than outdoors in summer. As found in the study, *liwan* - 35˚C, outdoor - 37 to 39˚C. Arcaded corridors guide the breeze well. **Shading** Shading of walls, openings, courtyards, *liwans* is the most effective strategy to keep interiors cooler. (Batterjee, 2010). This also helps in circulation of warmer air outwards (fig 30, 31).	  (26) Bahrain (27) Dubai   (28) Dubai (29) Bahrain   (30, 31) Bahrain
Wind Towers or *Badjir* Common in this region. Brings in cooler air from higher up which circulates through interior spaces; sometimes water is sprinkled in the surrounding walls to cool the air more (fig 32, 33). House in Moharraq has a large *badjir*, in *Majlis* or women's living room. Temperature below the tower was 1˚C cooler than rest of the room.	  (32) Muharraq (33) Dubai
High Windows High windows work as air fan, since lighter warm air rises up and escapes through high openings, allowing cooler air to enter the room from below (fig 34, 35, 36). ***Roshan*, Perforated Screen Openings** Perforated screen or ventilator or *roshan* very effective in reducing room temp; warm air rises up and escapes through it. The screen diffuses the direct sunlight and reduces heat gain (fig 37).	 (34) Dubai  (35) S Arabia  (36) Bahrain  (37) Doha

3 layers of perforated openings let air escape more frequently, depending on its temp. (fig 38, 39, 40).

(38) S Arabia



(39, 40) Bahrain

Monsoon Window/Horizontal Slit Window
The monsoon windows are small horizontal openings in the walls, which provide natural ventilation, indirect sunlight and privacy. It is mainly used on the exterior walls of 1st floor (fig 41).

(41) Bahrain

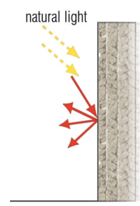
Roof Material
Roof consisting of mud, palm trunks, bamboo, mangrove wood and palm leaves provide good thermal insulation (fig 42, 43).

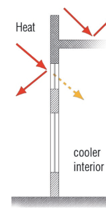
Roof Thermal Mass
Thermal mass of thick roof aid in delaying and reducing solar gain inside. Roof thickness is between 0.30m to 0.70m

(42) Dubai (43) Doha

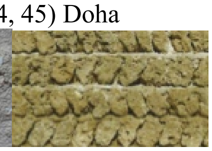
Wall Material
Walls of mud blocks, coral stone, palm trunks and straws act as very good insulators.
Poured in mud, or sun-dried mud blocks of rough texture. A variety of interior materials help diffuse sunlight (fig 44, 45)

Wall Thermal Mass
All four case study buildings have thick mud walls, typical of Middle Eastern architecture; wall thickness is from 0.40m to 1.00m. This gives high thermal mass to the building; thereby reducing and delaying heat gain inside (fig 48). Fursh coral, 0.07 m thick, was used with mud for infill panels between piers and for partitions. Dubai house had a difference of 2.7°C between outer and inner surfaces of exterior wall: •1-outer 35°C, •2-inner 32.3°C (fig 49).

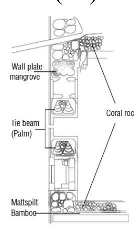


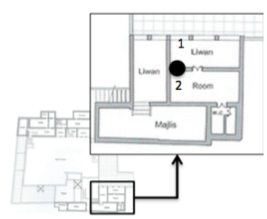


(44, 45) Doha



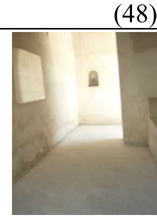
(46) Bahrain (47) Dubai

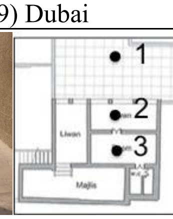




(48) Bahrain (49) Dubai

Floor
Mostly earth over compacted sand. Some exterior ones were of rough cut stone. Mud kept floor cool (fig 50, 51). In Dubai, surface temperatures of floors at various spaces were: •1-unshaded area 37.8°C, •2 shaded *liwan* 34.0°C, •3 -room 31°C (fig 52).





(50, 51) Dubai (52) Dubai

FINDINGS: ANALYSIS OF DATA ON TEMPERATURE, RELATIVE HUMIDITY AND AIRFLOW

Comfort Zone

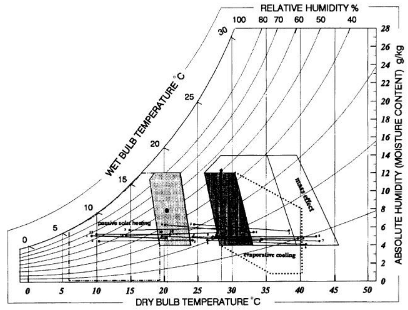


Figure 1 Application of Comfort Zone in Riyadh, Saudi Arabia
Source: (S. A. ALAJLAN, M. S. SMIAI, U. A. ELANI, 1997)

The comfort zones are similar for the hot-dry climates of these four adjacent countries, varying slightly from each other. The comfort zone of Saudi Arabia, which has the lower average temperatures among the four countries, has been taken as a standard for all countries.

The comfort values for different climatic elements can be considered as standard for Saudi Arabia as established by ALAJLAN, SMIAI, ELANI. According to Fig.1 summer temperature range is from 28˚C to 33˚C and Relative humidity ranges from 42% to 55%. With mass effect, and evaporative cooling, both of which is present and practiced in these buildings at a high level, the upper limit of the comfort temperature can be above 40˚C, and humidity can range from 15% to 58%.

Table 4. Temperature, Relative Humidity and Airflow

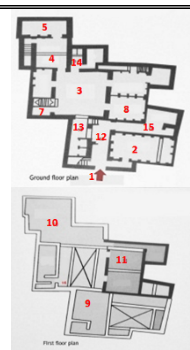
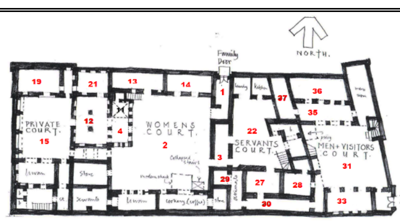
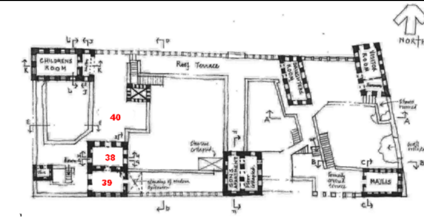
Market/Souk Waqif Doha, Qatar	Space	˚C	RH %	Air m/s	Al-Mulla House Al-Ahsa K.S.A.	Space	˚C		RH %		Air m/s
		Nov					Nov	May	Nov	May	May
	A	22	59	0.9		1	29	39	48	28.4	1.1
	B	24	48.9	0.4		1	26.1	40	55	34	1.7
	C	24	59	0.5		2	24.4	35.9	62	39	0.6
	C	26.1	52.6	0.4		3	25.9	38	57	32.3	0.7
	D	24.9	57.2	1.2		3	25.6	44	51	24.6	0.7
	D	25.3	53.4			4	23	36	64	33.3	0
	E	25.8	52.7	0.4		5	25	36	58	48	0
	F	26.9	46.6	0.4		7	27	39	43	30	0
	G	27.8	46.6	0.5		8	24.6	35	57	35.8	0
	H	26	45	1.3		9	28	38	47	37	0.6
	I	32	40.9	0.9		10	25.5	38.8	56.4	31.4	0
	I	29	43	1.5		11	25.8	39	60	31	0

Table 5. Temperature and Relative Humidity

Shaikh Issa House, Muharrq, Bahrain	Space	Space Name	˚C		RH %	
			Nov	May	Nov	May
	1	Entrance	24	35.7	0.73	30
	2	Family Courtyard	30.1	38	50.1	22
	4	Family majles	27	35	58.3	25
	11	Under the badjer	27	35	61.1	31
	12	Family majles	26.2	35	60	33
	13	Children living room	28.4	35.6	47.1	28.6
	14	Room for married son	28.6	35.8	45.6	28
	15	Sheikh courtyard	32.2	34.5	46.9	32.6
	19	Shaikh room	29.3	32.6	52.5	35.5
	21	The sheikh son room	27.9	33.3	57.4	31.3



22	Services courtyard	27.6	35.4	53.3	26.5
27	Kitchen	26.8	35.3	57.5	35.8
28	Business *majles*	26.5	34.9	60.8	27.7
29	Kitchen	26.5	35	58.5	21
30	Uncovered passage	26.6	35.4	60.1	26.5
31	Visitor court	26.4	35.3	52.6	20.4
38	Portico	28.9	35.7	46.9	29.5
39	Shieak living room	28.9	35	48.5	33
40	Open area	27.9	35.5	45.8	29.6

Table 6. Temperature, Relative Humidity and Airflow

Shaikh Saeed Al-Maktoum House, Dubai, U.A.E. Space	Space Name	°C Nov	°C May	RH % Nov	RH % May	Air m/s Nov	Air m/s May
1	Shaded side street	25.4	34.2	62.1	46.4	0	1.5
2	Unshaded side street	27.5	36.5	62.1	46.3	0	1.5
3	Open courtyard/plaza	30.6	36.3	42.2	46.3	1.2	1
	(A) Shaded	26.7	35.2	52.4	52	0	1.1
	(B) Unshaded	28	36.6	49.5	46.5	0	1.4
C	Summer room	27.5	34	48.1	52.4	1.2	1.5
D	Open roof, partly shaded	28.3	34	47.7	51	1.7	1.5

The analysis of data in **Tables 4, 5 and 6** is presented below.

Market or *Souk*, Doha, Qatar

It is a semi-outdoor space. As average temperature of Qatar is higher than Saudi Arabia, the comfort zone of Saudi Arabia well served the function of comfort assessment here, as in Figure 1. Data in market spaces met the comfort values in the beginning of winter. Market spaces' temperature range was 22-27.8°C and relative humidity 46.6-59%. Both the values are within the comfort range **as shown in Figure 1** As the Comfort chart suggested, in Figure 1, high thermal mass, night ventilation and evaporative cooling, all of which existed in the buildings, effectively helped the spaces be comfortable in summer and winter.

Al Mulla House, Al-Ahsa, K.S.A.

In winter, when the exterior temperature was low, the interior temperature was warmer and the reverse was observed for summer. Roofs of the house is made of wooden beams, palm trunks and leaves, palm leaf or bamboo mat which, topped by earth, acted as insulating material against the summer heat and the cold of winter. The measurements in various rooms show that internal temperature remains nearly constant around the day on a typical summer or winter day, while the ambient temperature has a large diurnal variation. House has no trees inside the courtyard now. It originally had some in the courtyard, which helped in more comfortable performance of the building. Relative humidity indoors was found to be lower than outdoors, which added to the comfort conditions.

Shiekh Issa House, Muharraq, Bahrain

It is seen that there are variations in data of different spaces depending on the orientation, proximity to courtyard, level of floor, *liwan* location, number and types of openings, etc. Indoor spaces are warmer in winter and quite cooler in summer than the outdoor readings. Temperature and relative humidity are within the comfort range.

Shaikh Saeed Al Maktoum House, Dubai, U.A.E.

Dubai was relatively more humid in both seasons, compared to other countries. In terms of comfort conditions, the building performance in summer was better than winter. In winter, temperature and humidity were almost within the comfort zone. The cooler breeze that was cooling the indoors was due to the presence of the creek nearby. As a result, relative humidity was within the comfort zone. In winter, airflow was almost nil in some spaces which were warmer than the breezier spaces.

Summer had higher airflow in the spaces of all case study buildings. Measurements of temperature and Relative Humidity were within comfort ranges. Comfort survey among the users of the buildings revealed that most of the users were comfortable within the shaded interiors of the buildings, in all four cases. As the survey revealed, only 5% to 10% of the present users preferred air-conditioning in these spaces in summer.

CONCLUSIONS

The traditional wisdom of how to solve architectural problems due to climate lying beneath the various architectural elements was to be unearthed through this research. The paper establishes that the traditional buildings of the hot-dry climate of the Middle East were and are still, able to function as very good examples of sustainable architecture, in terms of passive cooling. The study shows that the hygro-thermal performance in these mud buildings is very good, both in summer and in winter. It points out the various environmental strategies, materials and methods of construction of these buildings in question. Not much has been done in the research of this topic and hence this research is one of the few pioneering researches in Saudi Arabia. It is thus an important step towards rediscovering the traditional architecture of the Middle East from a new angle, the environmental point of view. Modern buildings of these countries are highly dependent on air conditioning that consumes massive amounts of electricity, and nearly 80% of household electricity is used for air conditioning (Taleb & Sharples, 2011).

The traditional strategies could easily be adopted for newer buildings that will help cool passively and thus save energy. The many towns that were sculpted with mud architecture in these places were, and some still are, in a ruined state. The respective governments are now restoring these. These examples of sustainable architecture will thus be sources for academic researches, professional inspiration as well as tourism, for years to come.

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Thermal Characteristics of a Vernacular Building Envelope

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ABSTRACT

Climate responsive building design is determined by the local micro-climate and the ability of the building envelope to regulate the indoor thermal environment. The building envelope characteristics are based on the available/accessible building materials and technology. Studies on vernacular architecture across the world showed that wall configurations and the thermo - physical properties of the building materials are used intelligently to maintain comfortable indoor comfort across the seasonal weather variations. Vernacular buildings of North-East India are naturally ventilated. Hence, it is important to find out an optimum wall configuration which will provide enough time lag, reduced discomfort hours as well as optimum thermal performance of these buildings. Various studies on building simulation/modelling show that building dynamic simulation tool can be effectively used to study the building envelope characteristics. In this study, a typical vernacular building in warm and humid climatic zone of North-East India has been considered to study the effect of thermo - physical properties of wall, thickness and material assembly on the indoor environment. Solar energy modular simulation tool TRNSYS 16 is used to carry out the simulations of this building with an objective to improve the indoor thermal environment. Building model is generated in TRNSYS and parametric simulations for different wall characteristics by varying thermo - physical properties and thickness of wall, and insulation thickness on external wall are carried out. Simulation results are obtained in terms of temperature profiles inside the different zones of the buildings. Indoor temperature profile of the building with best suggested wall configuration shows reduction in indoor temperature compared to the base case. In this study, it is also found that other climate oriented features such as shading mechanism like over hangs (very common feature in vernacular buildings) significantly influence the thermal performance of walls.

INTRODUCTION

Thermal performance study is one of the critical aspects of vernacular houses. These structures are evolved through generations, addressing the micro climate variations and also satisfy the needs of habitats (Singh et al., 2009a). Thermal performance of a building refers primarily to how well a building is insulated from the external weather conditions in order to achieve a comfortable indoor temperature. This can be achieved by keeping the internal temperature higher or lower than the external temperature as per the requirement of comfort temperature. Building design is greatly influenced by the severity and climatic variations leading to the need for integrating the building thermal design with the overall design process, helping the designer to decide at the beginning of the design process to bring the built space into comfort conditions (Al-Homound, 1997; Liu et al., 2010). The important parameters required for the design of energy efficient buildings are walls, roof, placement and size of openings, and shading devices (Charde and Gupta, 2013)**.** Building envelope like walls and roofs have important role to play in the heat transfer process between the indoor and outdoor environment of the building. Due to the quest for achieving better thermal comfort standard inside the building leads to higher heating and cooling energy requirements. Borah *et al.* reported that energy consumption for heating will be higher at higher base temperature and the energy consumption due to cooling of the buildings will be higher at lower base temperatures in the buildings of North-East India (Borah et al., 2015).The components of the building envelope can be used as the most effective way of controlling the indoor temperature of the building (Dutta, 2001). Simulation tools such as TRNSYS can be used effectively to study the effect of building envelope characteristics on indoor thermal environments. Singh *et al.* have done thermal performance simulation of three vernacular buildings at different bioclimatic zones of the north-eastern region by using TRNSYS simulation tool (Singh et al., 2009b). Simulation results concluded that the houses are fairly comfortable in pre-winter and pre-summer months compared to winter and summer months and successfully compared with the experimental results. Kalogirou *et al.* investigated the effects of the application of building thermal mass in Cyprus by modeling and simulating a typical house with the TRNSYS simulation program (Kalogirou et al., 2002). Jindal *et al.* analyzed the thermal performance of non-conditioned building of cold regions by using various insulation thicknesses at different positions of walls and roof. It is found that the thermal comfort for the three cold stations i.e. Srinagar, Shimla and Shillong cannot be ensured in the month of January if the building is not insulated (Jindal et al., 2013). The effect of insulation thickness on external walls in different seasons of the year in different climatic zones suggests that optimization of insulation thickness on external walls with respect to cooling loads is found to be more appropriate for energy savings compared to the heating loads (Bolatturk, 2008; Ozel, 2011; Yu et al., 2009). Al-Sanea *et al.* investigated the effects of location of thermal mass in insulated building walls on total and peak transmission loads, time lag, decrement factor, and dynamic resistance under the steady periodic conditions using climatic data of Riyadh. It is found that for a given thermal mass, a wall with outside insulation provides better overall performance than a wall with inside insulation (Al-Sanea et al., 2013). Asan investigated the effects of wall's insulation thickness and position on time lag and decrement factor. It is found that insulation thickness and position have intense effect on time lag and decrement factor (Asan, 1998). Axaopoulos *et al.* analyzed the thermal behavior of external walls using TRNSYS and determined the optimum insulation thickness for the external walls of a residential building in Athens, Greece, considering wall construction, orientation, wind direction and the position of insulation (Axaopoulos, 2014). Huang *et al.* found that the variation in the window to wall ratio for different orientation results into different economical thermal insulation thicknesses of building envelope (Huang et al., 2014). It is also found that the optimum performance can be achieved by considering the windows-to-wall ratio, house orientation, types of insulating materials and windows in addition to the impact of the windows and walls.

Building energy simulation tools are widely used for thermal performance study of building. In this study, a building model generated in TRNSYS 16 is used to analyze the indoor thermal environment of a typical vernacular building at Tezpur, in warm and humid climatic zone of North-East India. Most of the houses of the region are constructed in direct response to the climatic constraints and are naturally ventilated (Singh et al., 2010). A building model is prepared based on the inputs like building construction details, thermo-physical properties of building materials, wall thickness and insulation thickness on external wall using TRNSYS simulation tool. The layout of the building considered for the base case is shown in Figure 1. Windows on the house are distributed on all the facades. It is a single zone house with flat roof and single glazed windows. Since the vernacular house is naturally ventilated, so auxiliary heating, cooling and mechanical ventilation are kept off for all the simulations and the zone air temperature is considered as the primary output parameter.The simulation provides the results in terms of hourly temperature profile inside the zone of the building. Indoor temperature variation for all the simulations is compared with the base case and the results are analyzed to obtain the optimum design parameters. An optimum thermal performance of the building has been achieved by integrating the building optimum design parameters.

METHODOLOGY

Vernacular buildings are constructed across the world based on the local climatic condition. Vernacular buildings are the structures built by local people using locally available material and affordable technology to deal with the local and day-to-day needs (Singh et al., 2009a; Singh et al., 2010). Studies on vernacular architecture reveal that wall configurations and the thermo-physical properties of building materials have a great influence on indoor temperature. In recent times due to quest for achieving better thermal comfort; energy consumption is increasing in buildings. So, it is important to study thermal performance of vernacular buildings with varying building elements which will provide maximum comfortable hours inside the building. In this study, a typical vernacular building of warm and humid climatic zone of North East India is modeled in TRNSYS. Figure 2 represents the methodology followed to carry out this study. Table 1 represents the thermo-physical properties of the materials used for the simulation and Table 2 represents the wall configurations considered for the simulations. First a base case model of the vernacular house is selected to carry out the simulation.

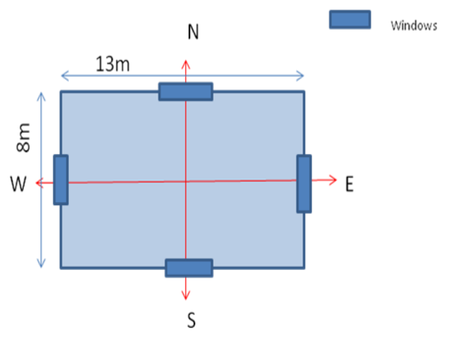

Figure 1 2D layout of the house with single zone

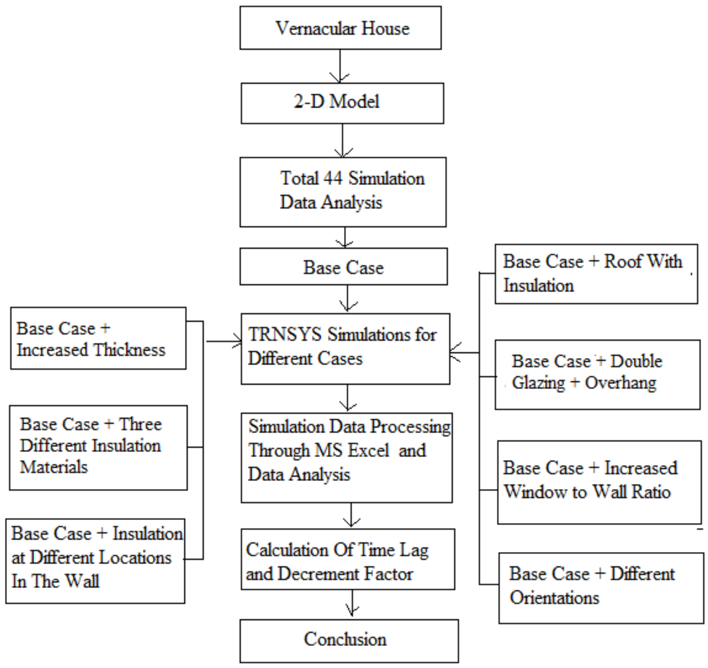

Figure 2 Methodology of the study

Table 1 Thermo physical properties of the materials used for simulation

Materials	Conductivity (W/m-K)	Thermal capacity (kJ/kg-K)	Density (kg/m^3)
Brick	1.301	0.84	2000
Aerated concrete (floor 0.127m thick)	0.289	0.84	1000
Light concrete (roof 0.127m thick)	0.120	0.84	400
Plaster	1.390	1.00	2000
Extruded Polystyrene, Insulation1	0.0278	1.47	30
Cell Glass (High density), Insulation 2	0.061	0.84	250
Polyurethane, Insulation 3	0.022	1.47	35

Parametric simulation studies are carried out by using TRNSYS 16 simulation tool. The standard building subroutine TYPE 56 has been used for the simulation (Singh et al., 2009b). The material properties listed in Table 1 and 2 are used as input parameters to generate the building model. For carrying out further simulations, base case model is used with various design modifications. Figure 3 shows the different scenarios for which the base case model is carried out. The different scenarios considered for the simulation are (i) increasing the wall thickness of the base case (ii) adding three different insulations on the wall of the base case (iii) placing the insulation at three different positions of the wall of the base case (iv) replacing the single glazed windows of the base case with double glazing and providing overhang on the windows (v) increasing the window to wall ratio (vi) providing insulation to the roof of the base case and (vii) considering four different orientations of the house. The infiltration for this house is kept at 3 ACH (air changes per hour) for all the simulations.Since the house considered for the simulation is naturally ventilated so the zone temperature is considered as the main output parameter. The surface temperatures of the wall are also obtained as output parameter.

Table 2 Wall configuration considered for the simulation

Case	External wall configuration (from inside to outside)	Overall heat transfer co-efficient (U) (W/m^{2}K)
Base case	Plaster (0.01m) + brick (0.127m) + plaster (0.01m)	3.545
Base case + A1 (increased thickness)	Plaster (0.01m) + brick (0.254m) + plaster (0.01m	2.633
Base case + A2 (increased thickness)	Plaster (0.01m) + brick (0.381m) + plaster (0.01m)	2.094
Base case + A3 (increased thickness)	Plaster (0.01m) + brick (0.508m)+ plaster (0.01m)	1.739
Base case + B1 (wall with insulation 1)	Plaster (0.01m) + brick (0.127m) + insulation 1 (0.05m) + plaster (0.01m)	2.164
Base case + B2 (wall with insulation 2)	Plaster (0.01m)+brick (0.127m)+ insulation 2 (0.05m) + plaster (0.01m)	2.748
Base case + B2 (wall with insulation 3)	Plaster (0.01m) + brick (0.127m) + insulation 3 (0.05m) + plaster (0.01m)	1.972
Base case+ increased window area	Plaster (0.01m) + brick (0.127m) + plaster (0.01m)	3.545
Base case + double glazed windows	Plaster (0.01m) + brick (0.127m) + plaster (0.01m)	3.545

RESULTS AND DISCUSSION

The vernacular house in warm and humid climatic zone is constructed with different wall configurations and various parametric evaluations have been done to analyze the effect of different wall configurations on the zone temperature. Analysis on the effect of window glazing, window to wall area ratio, providing roof with insulation on the zone temperature is carried out. Simulations are also carried out for different orientations of the building. The two very important characteristics, i.e., time lag and decrement factor, which determine the heat storage capabilities of any material, are also calculated. Simulation data for entire 8760 hours (i.e., one year) is obtained and the results in terms of temperature profiles are analyzed for January and July as the representative month for winter and summer seasons respectively. In this study, zone temperature is the main parameter around which analysis has been done. Figure 3(a) represents the variation of daily minimum zone temperature for all the days in the month of January. It is observed from the profile that variation in overall heat transfer coefficient (U value) depends on thickness and also the zone air temperature is higher in case of the wall with lower U-value, i.e., with decreasing U value, the daily minimum temperature of the zone increases which is desirable in winter. As we know that lower U value provides maximum resistance to the heat flow, hence, reducing the heat loss from inside the room to the outside air. So, it can be concluded from the Figure 3(a) that with the increase in thickness of wall, thermal inertia comes into play and consequently increases the time over which heat gain and loss takes place. This has also effect on the comfort conditions as occupants feel minimum thermal shock with noticeably varying outdoor thermal environment. So, for naturally ventilated buildings due consideration must be given to thermal inertia. Figure 3(b) represents the variation of daily maximum zone temperature for all the days in the month of July. It is observed from the profile that the temperature is lower in case of the wall with lower U-value (maximum thickness), i.e., with decreasing U value, the daily maximum temperature of the zone decreases which is reverse in the case of winter. With lower U value, heat gain from the outside air is reduced and thus the maximum temperature inside the room is low. Thus, from both the figures, it can be concluded that, the wall needs to be selected with U value as low as possible (with optimum thickness to maximize the effect of thermal inertia) to reduce the heat loss from inside the room in winter and heat gain from outside to the inside of the room in summer.

Figure 4(a) and 4(b) represent the daily minimum and daily maximum zone temperatures for each day of the month of January and July respectively. It is observed from the figures that 0º and 45º and 90º and 135º orientation shows similar temperature profile. For orientation 0° and 45º, minimum and maximum indoor temperature decreases leading to decreased indoor temperature swing. This happens because with change in orientations of the building the surface area of the external wall exposed to sun varies and so the heat gain. Since, the selected building is rectangular in shape and of single zone the effect observed here is low. It is found from literature that in the case of multi-zone building with different shapes (L, U, C and H etc.) the variation in indoor temperature is significant. Hence, it is suggested to decide the building orientation wisely before construction to maximize the use of solar passive techniques in the building thus improving energy efficiency and thermal comfort. Figure 5(a) and 5(b) represent the minimum and maximum inner surface temperatures for each day of January and July month respectively. Here, insulation is added to the base case and placed in three different positions (i.e., inside, middle and outside) of the wall. Figure 5(a) shows that in January (i.e., in winter) when insulation is placed at the outside surface of the wall, the minimum surface temperature of the wall has increased compared to the wall when insulation is placed at the middle and inside position because of thermal inertia plays its role. It is observed from figure 5(b) that in July (i.e., in summer) also when insulation is placed at the outside of the wall, the maximum temperature is lower compared to the insulation at middle and inside wall surface. Thus, it is observed that both in summer and winter months, placing insulation at the outside of the wall, shows better thermal performance, out of all the three cases (combined effect of thermal inertia and insulation). Furthermore, it is also observed that there is not much difference when insulation is placed at the middle position of the wall.

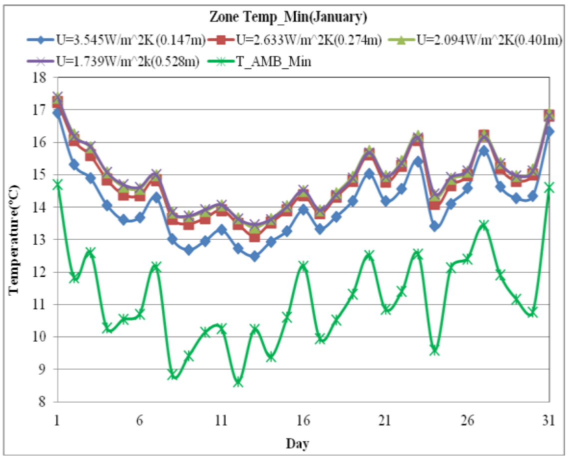

Figure 3(a) Daily minimum zone temperatures for different wall thicknesses

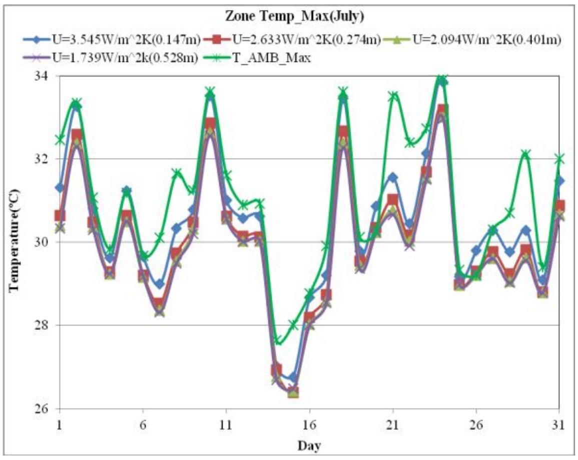

Figure 3(b) Daily maximum zone temperatures for different wall thicknesses

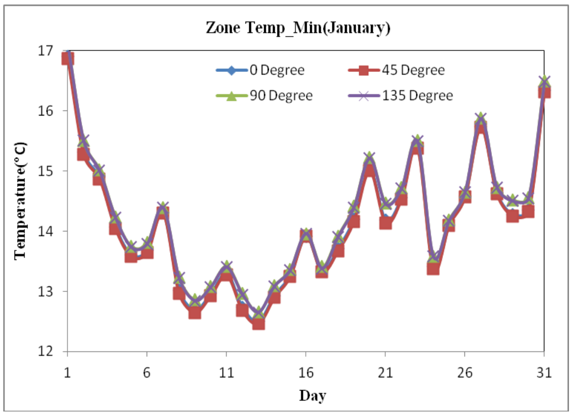

Figure 4(a) Daily minimum zone temperatures in January for the four orientations

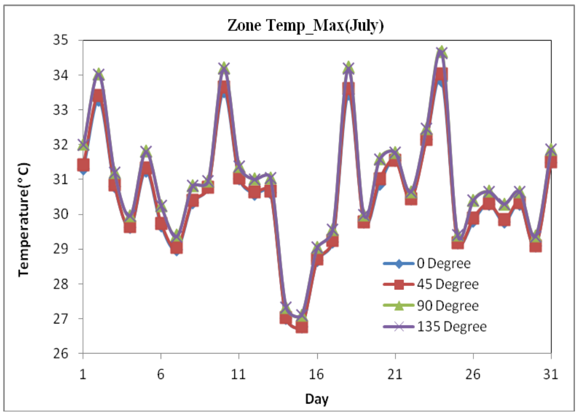

Figure 4(b) Daily maximum zone temperatures in July for the four orientations

Figure 6(a) and 6(b) represent the daily minimum and maximum zone temperatures in January and July respectively for different window to wall ratios. The windows are single glazed and window to wall ratio increases from 20 to 80%. It is observed from figure 6(a) that in January with the increasing window to wall ratio, the zone temperature is decreasing. This happens because with the increase in glazing area heat loss increase from inside to the outside environment. It is observed from figure 6(b), that the zone temperature increases with increasing window to wall ratio because heat gain is more from the outside environment. These two observations clearly indicate that both in summer and winter higher window to wall ratio leads to uncomfortable conditions inside the room. Hence, optimum window to wall ratio needs to be chosen so that in summer there is minimum heat gain and minimum heat loss in winter. Figure 7(a) and 7(b) represent the daily minimum and daily maximum zone temperature for January and July months respectively, when single glazing on windows have changed to double glazing. It is observed from both the figures that the increase in temperature is more prominent in winter because low altitude of the sun allows direct sunlight to enter into the room and increases the thermal gain thus temperature of the indoor environment. Moreover, both the overall heat transfer coefficient and solar heat gain coefficient comes into consideration for glazing. Though, for double glazing, the SHGC (solar heat gain coefficient) is lowered by only 10 % in comparison to single glazing but the effect due to low SHGC is compensated by low U value (U value of single glazing is 4.8 and for double glazing is 2.7). So, in winter the double glazed windows perform better by trapping the absorbed heat inside the room. However, in summer, the solar heat gain coefficient allows the direct sunlight to enter the room through the window and make the room hotter. Hence, in summer it is advised to have appropriate overhang on the window to block the direct sunlight to enter inside the room.

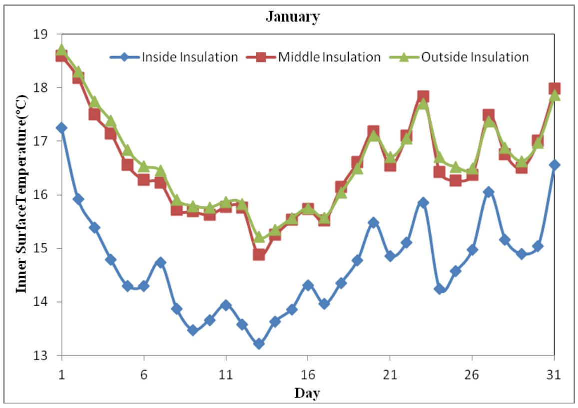

Figure 5(a) Inner surface temperatures for January for three different positions of insulation

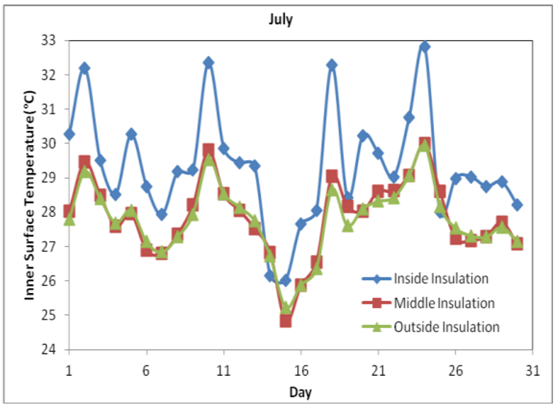

Figure 5(b) Inner surface temperatures for July for three different positions of insulation

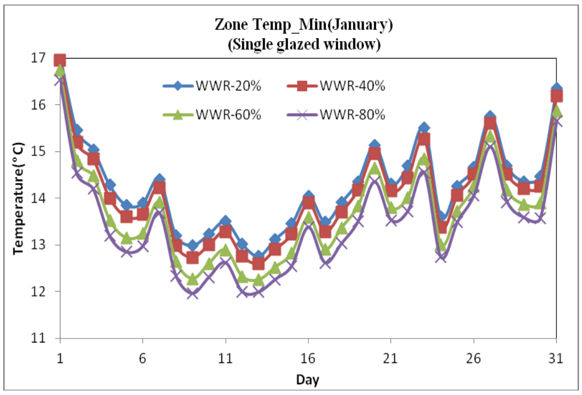

Figure 6(a) Daily minimum zone temperatures in January for different window to wall ratios

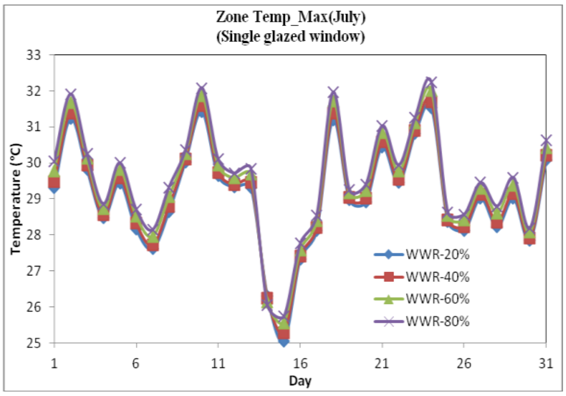

Figure 6(b) Daily maximum zone temperatures in July for different window to wall ratios

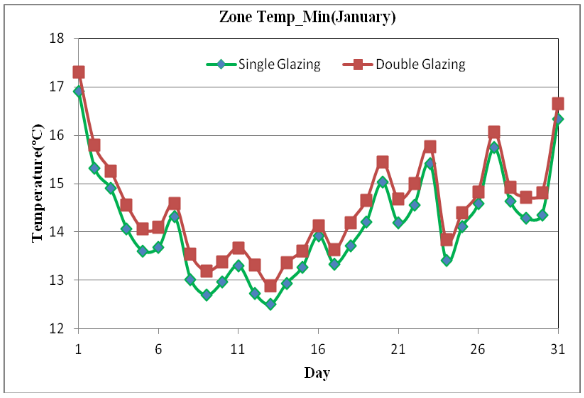

Figure 7(a) Daily minimum zone temperatures in January for double glazed windows

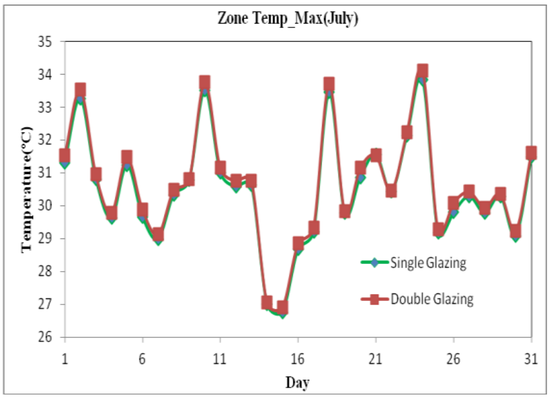

Figure 7(b) Daily maximum zone temperatures in July for double glazed windows

Figure 8 represents the effect on the zone temperature when the roof is provided with insulation. It is observed from the figure that the effect of insulation on the roof is negligible on the indoor temperature profile of the zone. This may be due to high infiltration in naturally ventilated buildings leading to negligible effect on the indoor temperature swing. Figure 9 represents the variation of time lag and decrement factor for different thicknesses of the wall. The variation of time lag and decrement factor is shown for two different materials. It is observed from figure 9 that the time lag increases with the thickness of the wall, whereas decrement factor decreases with the wall thickness. Moreover, both the materials are exhibiting different time lag and decrement factor. This indicates that time lag and decrement factor not only vary with the thickness of the wall but also with the material properties. For better thermal performance, time lag should be high and decrement factor should be minimum.

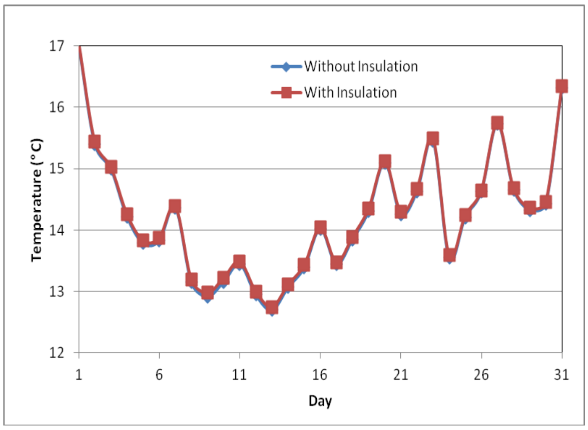

Figure 8 Daily minimum zone temperatures for roof (January) with insulation and without insulation

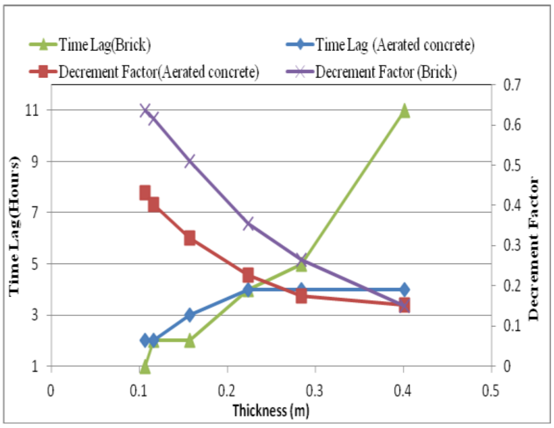

Figure 9 Time lag and decrement factor for different wall thicknesses

The effect of different insulation materials on inner wall surface temperature for a period of 24 hours (i.e., 1 day) in the month of January and July respectively has also been carried out. Three different insulation materials - extruded polystyrene, cell glass of high density and polyurethane are added with the base case and the inner surface temperatures of the wall are obtained. It is observed that in January (i.e., winter) month, the peak of minimum temperature is less in case of polyurethane as the insulation material, in comparison to cell glass and extruded polystyrene. It is also observed that in July (i.e., summer) month, the peak of maximum temperature for the wall with polyurethane as insulation material is lower than the wall with other two insulation materials. Moreover, the 24 hour swing in temperature throughout the day is less in case of polyurethane as insulation material. Hence, it can be concluded that with polyurethane as the wall insulation material shows better thermal performance both in summer and winter months. It is also observed that there is an increase in the temperature for the month of January (winter) when the windows are provided with overhangs. It is also observed that the maximum temperature in the month of July (summer) month is decreasing, clearly indicates that windows with overhang have a significant role to play by blocking direct sun light to enter the room in summer leading to decrease in indoor air temperature but in winter it allows sunlight to enter room thus increases the indoor air temperature.

CONCLUSIONS

Thermal performance analysis of building envelope is very important to evaluate indoor thermal environment of naturally ventilated buildings. The building envelope constitutes the major portion of the building through which maximum heat gain and loss occurs in both the extreme seasons respectively. In this study, a typical vernacular building of warm and humid climatic zone of North East India is considered. This study made an attempt to carry out the thermal performance analysis by varying building material parameters and their effect on the indoor environment. It can be concluded from the study that, with the increase in the wall thickness, the overall heat transfer coefficient reduces and also the overall heat transfer coefficient changes, when the thermo-physical properties of the material changes. It has been found that orientation has an important effect on the indoor temperature; because of different orientations, different area of external area is exposed to direct solar radiation leading to heat gain. It is also found that location of insulation on the wall have significant effect on the thermal performance, showing that insulation applied on the outside surface have less temperature swing. The effect of different insulation material on the wall surface temperature has also been studied and polyurethane has been found showing the best performance. This study also reveals that windows with double glazing have maximum effect in winter when the sun's altitude is less. Hence, if the window is replaced by proper shading mechanism then overall performance can be improved. It is found that increase in the window to wall ratio has significant effect on the indoor temperature swing. Increase in the window area leads to maximum hours of discomfort inside the building in both January and July months. It can also be concluded that providing insulation to the roof has negligible effect on the indoor temperature profile. Time lag and decrement factor are also calculated for different wall thicknesses. It is found that thermal mass of the wall and thermo-physical properties of the wall have a profound impact on time lag and decrement factor. The findings of this study also relate to the policy intervention and best practice needs to be followed in these types of building design. North-Eastern region is in development process and the construction sector is rising in unprecedented way. These types of buildings are well suited to the climatic factors as well as social requirements of the people of the region. Hence, the findings of this study could be useful to the policy makers, architects, and local people for designing better thermally comfortable buildings.

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Daylighting Analysis of Vernacular Architecture in Guizhou Province, China

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ABSTRACT

China has 55 minorities, most of whom have their own unique architecture. Due to urbanization these traditions are in danger and traditional dwellings are replaced with modern houses in the hope of better living conditions. By understanding and finding solutions to the problems emerging in these traditional dwellings and by using their features in a more sustainable and more adaptive way to local climate, living conditions could be improved without losing this unique culture. Due to its substantial minority population and varied terrain, Guizhou province in China has a rich source of different types of traditional dwellings. Dwellings representing the typical architecture of three different ethnic groups Han, Miao, and Dong were selected to conduct daylighting analysis. Measurements made during a field work helped to explore how the different building ways, folk customs, topography and other factors impact on architectural daylighting. With the help of the results, suggestions are made on how to reform existing dwellings under the corresponding architectural language and lifestyle, and what modifications should be made to meet the modern daylighting needs of occupants. Different scenarios are simulated using ECOTECT 2011 software (Ecotectt, 2011) to show the positive results of the changes suggested.

INTRODUCTION

China is a multi-ethnic country with a long history and a vast territory, during the thousands of years of its history a vast amount of varied residential building types have evolved. Different regions have different natural conditions and cultural background, which is reflected by vernacular dwellings all over the country. Over the recent decades, due to the acceleration of urbanization, modern architecture became more widespread. Modern architecture promises to accomplish a better living environment, but it contributes to the destruction of traditional vernacular dwellings. Traditional vernacular dwellings represent a valuable heritage and help to preserve the habits and folk-custom of ancient people. More importantly the ecological thinking and technical solutions of vernacular buildings are a significant knowledge source for the sustainable development of new settlements and an indispensable reference on terrain adaptation, climate adaptation and construction of passive energy-saving measures. To renew the vitality of a traditional vernacular dwelling, its adaptability to modern life and comfort must be improved. Daylighting is an important measure of building comfort. Because of limited building and technical resources available at the time they were constructed, traditional houses typically take advantage of natural light. However with changes in living habits and the improvement of living standards, original daylighting conditions are not able to meet the demands of the present. Improvements of vernacular dwellings' should also focus on enhancing daylighting condition, an area which needs to be researched in more detail. Few studies already have been conducted on architectural daylighting of Chinese traditional vernacular dwellings (Wang, Zhuo and Dac'y 2008, Duan, Lau and Ford, 2012, Lin, Li, and Chen, 2013), but it is a generally a neglected area of research to which this paper tries to contribute. There are many types of dwellings in different regions that have not been researched yet, from which this study is focusing on three typical types of dwelling characteristic of three ethnicities, a special group of the Han, the Dong and the Miao, all of which are characteristic to Guizhou Province, which due to its less developed infrastructure and economy was especially neglected. The principle aim of this research is to investigate the daylighting performance of three traditional vernacular dwellings and the factors influencing it, by means of on the spot data collection, analysis, software simulation, in order to suggest viable modifications of the original dwellings, to meet the occupants' lighting needs better. After introducing the characteristics of the locations of the field research, research methodology is explained. Results and analysis will then be presented, together with simulation, finally conclusions are made and suggestions for future improvements are given.

ETHNIC ARCHITECTURE AND LOCAL CLIMATE

The vernacular dwellings selected for the research are located in Guizhou province, in the village of Jiangchang, SanBao and Xijiang (Figure 1). The dwelling in Jianchang is a typical example of Han Chinese vernacular architecture and the 'tunpu' culture retained locally. The dwelling in Xijiang reflects the local architecture of Miao minority and is part of the world's largest Miao settlement while the dwelling in SanBao is typical of the Dong minority. All of the three ethnic groups have a history of hundreds of years and rich cultural traditions, which are reflected in architecture, clothes, food, folk beliefs and entertainment. Guizhou has a typical subtropical monsoon climate, where summer is hot, humid, and sunny and winters are relatively warm.

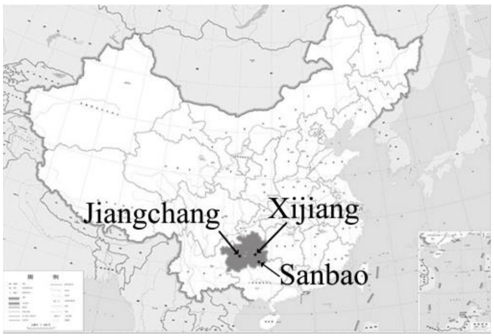

Figure 1: Location of Jiangchang, SanBao Dong and Xijiang Miao in Guizhou province, China

Each of the three dwellings chosen carry the main characteristics of the local traditional architecture. The main structure of the dwellings in Jiangchang consist of a wood structure and the building envelope is made of stone blocks. This is coupled with the most distinctive feature of these buildings, the thin slab stone roof, stacked layer upon layer. (Figure 2 (a)) The Dong minority's dwellings in SanBao Dong are almost solely constructed from wood, from the load bearing structure, through the inner envelope and wooden stairs. Only the kitchen is made of brick, which is usually attached to the main building. (Figure 2 (b)) Both the Han and Dong dwellings usually consist of two storeys, with living areas located on the ground floor and storage places on the first floor. In the Xijiang Miao village local houses are typical mountain buildings, wooden houses on stilts located mainly on a hillside, built row upon row. A unique feature of these dwellings is the semi opened balcony located outside of the living room with railings locally called as 'beauty's leaning'. Buildings usually consist of two to three storeys. The ground level is used for storage or for livestock, accommodation and main living spaces are on the first floor while upstairs is used for storage. (Figure 2 (c))

Figure 2*:* Traditional Dwelling in Jiangchang (a), SanBao Dong (b) and Xijiang Miao (c)

FIELD SURVEY METHODOLOGY

The field research was conducted during the summer, data collection took place from 4th and 9th July 2013, over two days in each location. Daylighting data were collected through spot measurements using Digital LUX METER (TES 1330A) illuminometers. Data collection focused on the floor where main living spaces were located, in the Jiangchang and Sanbao Dong on the whole ground floor, while for the dwelling in Xijiang on the first floor, as for places used for storage or livestock daylighting is not of crucial interest and thus was omitted in this research. In the collection of illuminance values, the researcher took account of individual rooms and functions to determine the number of measuring points. A grid was drawn on the floor plan of each room, with intersection points not further apart than 1 meter, illuminance values were collected at each intersection at 800 mm above floor level, according to the reference working surface level suggested by the Standard for daylighting design of buildings (China, 2013). Inside and outside illuminance data were collected simultaneously by a pair of field researchers. To reduce error and to ensure the accuracy of the data, three complete sets of illuminance measurements were taken in each room under overcast conditions. No additional artificial lighting was used during measurement times. Outdoor illuminance values have drastic fluctuations, even under overcast conditions, resulting in change of indoor illuminance, but for the same test points, the ratio between the indoor and outdoor illumination value should remain stable. Ratio of outdoor and indoor illumination is called the daylight factor (DF), and it will be used as a basis for research daylighting performance in this research.

DATA ANALYSIS

Indoor daylighting condition is influenced by various factors, such as the proportion of the space (depth and width), presence of shading device or outside structures providing shading, the area ratio of windows to floor, the presence of grilles or wooden decoration on the windows and the reflectivity of the walls. The analysis of data focused on these factors.

The first step was to obtain the plan of the dwellings through measurements taken with Leica Disto™ D2 laser ruler and tape measures, layouts and section plans were drawn. Details of the size, position and form of the daylight openings in the house and the presence of shading devices were also recorded.

The vernacular dwelling in Jiangchang village has a simple rectangular layout (Figure 3 (a)). The dwelling is surrounded by a stone wall forming a courtyard. Building layout is simple, only consisting of three rooms arranged next to each other in a linear fashion, with the living room located in the middle facing south. The shape of the bedrooms is long and narrow, the depth reaching 7.5 meters, and the rooms have windows on both of their south and north wall. A bungalow was later built on the southeast corner of the main building. The windows are all the same size of 1300mm (w) *1000mm (h) decorated with grid patterns and with window sills' height at about 1.1 meters. The layout of the dwelling in SanBao Dong is also symmetrical with the total of three bays, the main living area is located in the middle with the main entrance facing south. (Figure 3 (b)) The living room is surrounded by two-two bedrooms on both sides. Each bedroom has only one window the size of 850mm (width) * 900mm (height) and are equipped with safety grilles. Windowsill is relatively high, reaching 1.4 meters. The dwelling selected in Xijiang is a three floor pillar supported building, the back side of the building is connected to the mountain, while the front of it is facing south. The whole design embraces the mountain terrain specifications. The plan is long with an axis from east to west and symmetrical layout. (Figure 3 (c)) In the middle is the main living room area opened on the south side with the 'beauty's leaning', which is connected to the rooms on its sides through a corridor. The kitchen is located on the west side. Window sizes vary on the first floor, with a width between 650 to 750mm and heights between 600 to 900mm. Window sills are at the height at 1 meter.

The three layouts are different and represent the local culture and adaptation to terrain, however there are some features which are present in all the three dwellings. The local subtropical climate of

Guizhou is quite wet, annual rainfall is around 1360 mm. In these wet conditions wood structures need to be protected, thus the presence of a roof overhang was observed at all the dwellings. In Jiangchang the building has a double pitch roof with 1.4-metres overhang on both south and north sides. In Sanbao Dong the south side of the building also has a 1.1 meter roof overhang while the overhang on the north side reaches the kitchens outer wall. In Xijinag it reaches 1.3 meter on both south and north sides. Inside separation walls are made of wood, with a quite dark colour due to the aging of the material. The size and shape of the windows vary but, in each case the glass has a decorative wooden pattern. In Jiangchang this has decorative function, while in the other two dwellings it is a simple pattern and is more part of the traditional way of window construction than a decorative function. Next the area ratio of windows to floor (A_W/A_R) was calculated, by dividing the total area of the windows (A_W) present in a room by the area of the room (A_R). As the national standard minimum requirement are given in fractions, results in decimals were rounded to fractions. (Table 1)

Illuminance data collected was processed first by getting the ratio between the indoor and outdoor illumination value of every test point, and then by taking the average of the three measurements as the measuring points on the daylight factor (DF) values. Based on the data obtained in this way daylighting contours for all the rooms tested were generated using the software package Surfer 8 (2004) and daylighting situation in all the three dwellings was analysed based on the DF isolux contours obtained with Surfer. Results are shown on Figure 3.

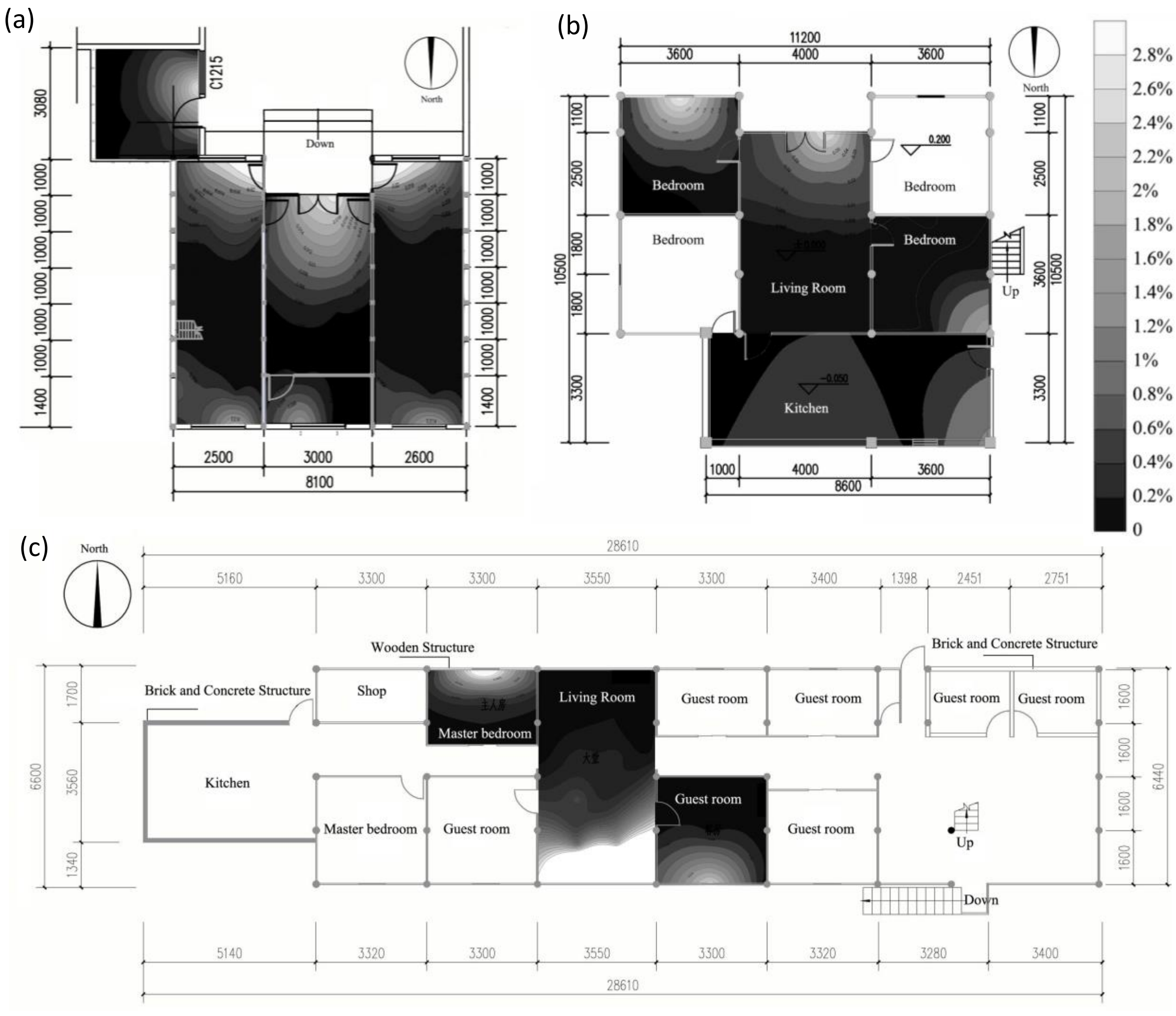

Figure 3: Floor plans and DF isloux contours of rooms tested in Jiangchang dwelling ground floor (a), SanBao Dong dwelling ground floor (b) and Xijiang Miao dwelling first floor (c)

Table 1. Area Ratio of Windows to Floor

Place	Room area (m^2)	A_W/A_R	A_W/A_R in Fractions
Jiangchang			
Living room	15.0	0.17	1/6
East Bedroom	18.5	0.15	1/7
West bedroom	18.5	0.15	1/7
Kitchen	4.2	0.38	1/3
Bungalow	9.0	0.33	1/3
Sanbao Dong			
Living room	24.8	0.08	1/12
East Bedroom	13.0	0.06	1/16
West bedroom	13.0	0.09	1/11
Kitchen	28.4	0.07	1/14
Xijiang Miao			
Living room	23.5	0.34	1/3
East Bedroom	7.6	0.08	1/12
West bedroom	10.6	0.06	1/16

FINDINGS

The analysis showed that daylighting of these dwellings has the following problem:

The minimum daylight factor (DF_{min}) cannot meet the residential building standard

The architectural lighting design standards for residential buildings (China, 2013) sets the minimum value of daylight factor at DFmin=1%. From the data analysis, it can be seen that, the minimum value of daylight factor of the three dwellings do not meet the specification above in none of the rooms, with DFmin values ranging from 0.01% to 0.26%. Living rooms in all the three dwellings have a better daylighting performance than bedrooms, where daylighting conditions are not favourable.

Concluding from the analysis of the data, the following factors have negative effects on daylighting in the three traditional dwellings:

1) **The size and proportions of the rooms.** The face width of the rooms can be considered normal according to modern building standards, however great depth, reaching even 7.5 meters in Jiangchang, results in not good daylighting condition and areas with almost no light. Great depth is especially characteristic and thus problematic for the living rooms, which are the main living area and such should have the best daylighting performance.
2) **The colour of the interior wall.** Internal partition walls are made of wood, which darkened after prolonged use. The dark colour of the partition walls makes the reflection of natural light more difficult, while also contributing to a feeling of darkness.
3) **The size and construction of the daylight openings.** According to the National standard minimum requirement of the area ratio of window to floor (GB50096-2011, 2011) needs to reach 1/7 in general. Normal values for bedrooms are considered to be between 1/6-1/8, and 1/4-1/6 for living rooms. Looking only at this value the situation in Jiangchang dwelling is quite favourable, with all rooms meeting national minimum requirements, however the great depth of the rooms disturbs the daylighting effect. The values are a lot below the standards, ranging from 1/11-1/16, only in one case is the value in the acceptable range, for the living room in Xijiang Miao dwelling. Besides the size, the presence of a wood pattern on windows, reduces the daylight effect even further, by reducing the area of the window.

COMPUTER SIMULATION

Simulation description

To show the effect of the identified problems and to find the best solutions for improving daylighting conditions in the dwellings, simulations were carried out using ECOTECT 2011 software

(Ecotectt, 2011). During simulation, factors identified before to cause problems were impoved compared to original measurements and the positive effect of these changes were evaluated. Three factors were selected to be variable in the experiment, the depth of the room, the colour of the interior wall and the presence of the grid on the window. (Table 3) The layout and original filed measurements of the Jiangchang dwelling were used as the control group for the simulation, as many of the factors causing daylighting problems were prominent. However simulation was only carried out on this one dwelling, findings should also reflect the other two dwellings, due to the similarity of the emerging problems, the similarity of outside conditions and the same orientation. All the simulations were done under the conditions summarized in Table 2.

Table 2. Simulation Conditions

Name	Value
Location	26.14 degrees north, latitude 105.55 degrees east
Daylight Climate zone	IV Daylight Climate zone
Critical illuminance value	4500lux
Illumination sky model	CIE cloudy sky

Table 3. Simulatin options descriptions

Simulation	Variable changed	Change compared to original situation
Control group	None	Variables are the same as in original conditions: bedroom depth 7.5m, living room depth 5.1m, walls are dark stone with dark wood, reflectivity rate is 0.16, grid is present on the window shown by transmission rate of 0.5, doors open
A	Room depth	Bedrooms' depth is reduced to 6 m, livingroom's depth is reduced to 3.6m
B	Indoor wall color	Indoor walls are set as painted a light wood color, the light reflectivity increases to 0.4
C	Window grid	No grid on the windows, transmittance rate increases to 0.7
D	All the above	All the above variables are present at the same time

Simulation results and analysis

Analysis of the different models resulted in five situations showing the impact of each variable on the indoor daylighting condition. Compared to Figure 3 (a), the indoor distribution curve of daylight factor of the control group has a similar distribution trend of the original dwelling (Figure 4 (a)). Although there are still some deviations in the data, the pattern of DF in the simulation experiments can be considered consistent with the existing situation. To show the effect of the different variables on the daylighting condition, average DF and the percentage of all values between DF 0-1% (under standard), DF 1-2% (gloomy but acceptable conditions) and DF 2% (reasonably good) were calculated and compared. When a higher percentage of the values are in the higher DF range the effect of the change of the variable can be considered stronger. (Table 4)

Table 4. Change in Daylighting condition for different simulation described by the percentage of values in different DF ranges

Simulation	Average DF	DF between 0-1%	DF between 1-2%	DF above 2%
Control group	1.77%	47.79%	24.64%	27.56%
A	2.26%	23.05%	39.78%	37.16%
B	2.00%	33.03%	36.04%	30.93%
C	2.27%	31.59%	32.33%	36.08%
D	3.67%	6.3%	32.76%	60.94%

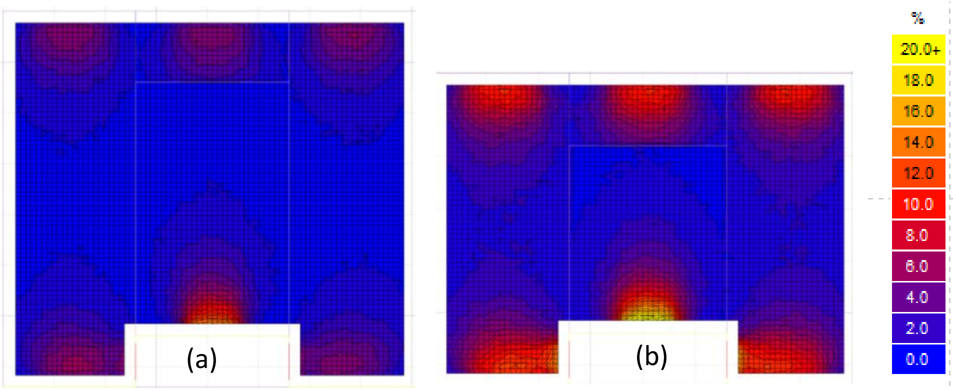

Figure 4: Dayligt factor simulation results, control group (a) and simulation D, all variables changed (b)

The impact of room depth on daylighting: The change of the room depth affected the distance between the north window and the south window, and thus the area ratios of window to floor. From all the variables changing the room depth has the most positive effect on daylighting. The percentage of DF values between 0-1%, values, under the accepted standard, reduced to 23% while the percentage in the range of above 2% increased to 37.16%. Reducing the depth allows the same amount of light to be able to meet the needs of indoor better. Lighting distance on both sides also reflects the advantages of two-sided lighting.

The impact of interior wall surface reflectivity on daylighting: After the colour of the interior walls is changed to a light colour, their reflectivity increases from 0.16 to 0.4 resulting in the increase of the area with a value of DF in the range of 1% to 2%, however it's a smaller increase than in the case of the other two factors. The increase of the interior walls' reflectivity allows better diffuse reflection of the light entering through the windows and the doors.

The impact of grids on the window on daylighting: The grid on the window reduces the area of the window, but since its area is difficult to calculate, it was simulated by altering the transmittance rate for testing purposes. Simulation results showed that when there is no grid present, DF values near the windows increased and only 31.59% of DF values are under the standard compared to the original 47.79%. Removing the grid can increase the injection of indoor natural light and thus can positively affect daylighting condition.

Figure 4 (b) shows the cumulated effect of all changes. It can be seen that daylighting situation improved significantly. When applying all the changes together only 6.3% of DF values are under the standard and more than 60% of the DF values are reasonably good range. Considering the above results suggestions are given for future improvements.

Suggestions for improvement

By analysing the results, it can be concluded that both the large depth and dark interior wall of the traditional dwellings in the three villages have a negative effect on daylighting conditions of the residential living areas. Also, the traditional carved wood decoration and safety grills on the windows increase the self-shading of these houses and decrease the amount of light penetrating the rooms even in the case of an appropriate window area ratio in Jiangchang village. Not to mention in the other two cases, where the ratio of window to floor is much lower than suggested by modern building standards. These dwellings cannot guarantee even the basic lighting requirements of daily life.

Based on the data analysis and the results of the simulation future refurbishment or new build projects should be carried out including measures to increase the amount of sunlight and to improve the natural daylighting condition. To increase the comfort of occupants the following measures can be taken:

The amount of sunlight is most influenced by the area ratio of window to floor. The easiest measure would be to increase the window size. In the case of rebuilding traditional houses, this can be done to an extent when the appearance of the traditional dwellings doesn't loose its originality. However when old dwellings are refurbished this could be problematic.

Another solution can be to replace the original glass of the window with high transmission glass and to replace the fixed carved wooden grilles with ones that can be opened at times, thus daylighting in the rooms can be improved without changes that influence local building style.

Under modern living conditions too large depth of the rooms is not useful anymore for the occupants of these dwellings. It was observed that due to shortage of daylighting the opposite end of the room is usually used as storage only and is not part of the active living space. The most hands on solution would be to reduce the depth of the room, as this is the factor having the biggest positive influence on daylighting condition, but it is a very difficult and complicated job to carry out as part of the refurbishment. Therefore, this modification is generally possible in case of new built dwellings following the traditional design style, but there it should be the primary consideration.

The change in the surface of indoor wall is a more feasible suggestion during refurbishment. In terms of traditional wood building material and stone, plastering on all walls seems too simple and rude, and it would destroy the native beauty of these residential dwellings. Despite painting the walls white would have a stronger positive effect on daylighting, taking in consideration the consistency of the traditional style, the solution suggested here is to clean the wooden walls and repaint them with wood protective paint. Such a change may not only improve the indoor lighting, but also protect the building components.

CONCLUSION

This research consisted of two parts. In the first part lighting data of the traditional dwellings in Jiang Chang Village, SanBao Dong and Xijiang Miao was collected during a field research. Based on the data collected features and influential factors of lighting were studied in detail. The other part was to study the lighting variables of the vernacular dwellings. A simulation experiment was carried out using ECOTECT software, which verified futures assumptions of influencing factors of daylighting. Renovation suggestions, such as cleaning and treatment of wood walls, movable grilles and replacement of the window glass, were given, which measures will improve daylighting situation. In case of new built dwellings using the traditional style, primary focus should be on reducing room depth. All these measures will have a positive effect on occupant comfort and thus contribute to the protection and preservation of these traditional dwellings, and could also be on dwellings in other parts of China. However, further reserach is needed in this area, to understand daylighting conditions in different dwellings and to explore more possible solutions to improve it.

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Changes in Culture and Architecture from Vernacular to Modern: M.P., India

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ABSTRACT

India is known for its rich cultural heritage. The culture plays an important role in defining the architecture of a place or people with time. Madhya Pradesh is one of the states of India. The objective of the paper is to study the changes in culture and architecture from vernacular to modern of Madhya Pradesh. Vernacular architecture has been evolved through a process of trial and error for ages. In Methodology the vernacular and urban dwellings are documented and analyzed on various parameters of culture and architecture. The dwelling of potters and bamboo workers are selected from vernacular and urban settlement. The two typical dwelling from BHEL, Bhopal is selected from an urban settlement. The result focuses on influences of urbanization and globalization which brought threat to cultural identity. The urban settlements are designed according to the economic status of the residents without considering their culture. The analysis is to adapt the appropriate technology using locally available material and construction techniques for a sustainable development. It requires an innovative and creative approach to integrate vernacular into the modern architecture. The paper concludes by learning and appreciating the principles of vernacular architecture and integrating them with the contemporary knowledge and technology.

Keywords: culture, architecture, vernacular, modern, sustainable development

INTRODUCTION

Madhya Pradesh is one of the states in India which is centrally located. It is also known as heart of India due to its geographical location. Bhopal is the capital of Madhya Pradesh was formed in 1956. The border of this state touches five states: Gujarat, Rajasthan, Uttar Pradesh, Chhattisgarh and Maharashtra. The influences of these states are prominent in zones and architecture of Madhya Pradesh. Its culture can be divided in four zones such as Bundalkhand, Baghelkhand, Malwa and Nimar. Each zone has its own cultural identity such as language, dialects, customs, rituals and beliefs. The state is famous for its tribal arts and crafts. As per 2011 census of the state the population was 72 million and the tribal population is approximately 20 % of the total population.

Figure1 Map of India

Figure 2 Map of Madhya Pradesh

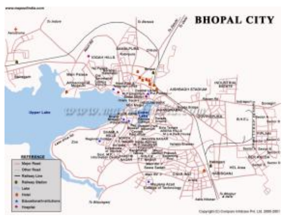

Figure 3 Map of Bhopal city

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CULTURE AND ARCHITECTURE OF MADHYA PRADESH

The tribal and folk traditions of Madhya Pradesh are reflected in the vernacular architecture. The state is known for its visual and performing arts, these art forms are closely associated with their beliefs, customs, religion and values. The singing and dancing are part of their day to day life. It is a community activity performed each day after the work to relax and enjoy. These activities have evolved the necessity of a community space like a courtyard or chaupal in their settlement pattern. These patterns resulted in a strong social binding within the community. Each tribe has its own way of settlement pattern on the basis of their culture and lifestyle like Saharia has circular, Bhil has scattered and Korku has linear. The central space in Saharia is 'chaupal' where grandparents chat and look after grandchildren while the parents are working on fields.

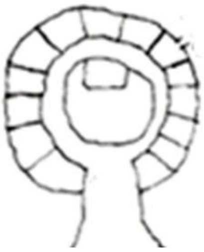

Figure 4 Circular pattern, Saharia

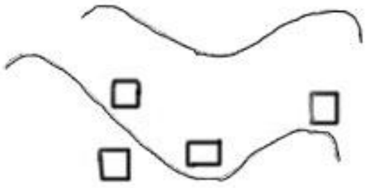

Figure 5 Scattered pattern, Bhil

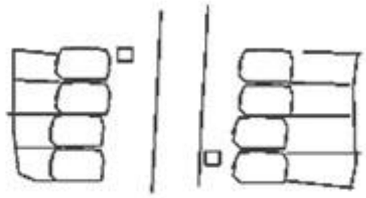

Figure 6 Linear pattern, Korku

Madhya Pradesh is famous for its traditional crafts like bamboo, wood, pottery, painting, metal casting, terracotta and textiles. The sarees from Mahaeshwar and Chanderi are famous for weaving whereas Bagh and Ujjain are famous for printing. The designs are evolved and inspired from the surrounding environment. The weaving pattern in Maheshwari sarees 'Laharia' is most dominating which is inspired from the holy river Narmada. These patterns of textiles are also reflected in the vernacular architecture. The sculpture and murals in the houses are not simply for decoration but are part of their rituals and beliefs. During the festivals and rituals the murals depicted on the walls are Pithora, Sanjha and designs on the floors are Mandana, Alpana and Rangoli. The tribals adorn their roof tiles with animals, human images and some figure which have something to do with witch-craft and evil spirits. Horses occupy a significant status in tribal life as symbol of power and force. It is depicted in different forms in murals, sculpture and even in the structural members of the built form. The bas relief figure of birds, flowers, trees and animals are depicted on the interior walls of houses. The clay figures are prevalent to mark both auspicious as well as inauspicious occasions. The paneled doors of single plank and wooden pillars are carved with the motifs of flora, funa and geometry designs. The Bas relief figure of animals, birds, trees, flowers and god-goddess are depicted on the interior walls. The trees are integral part of a house like a Tulsi chura in middle of a Hindu house, they also have medicinal values.

REFLECTION OF CULTURE IN ARCHITECTURE

The communities of potters, textiles, printer, waevers and bamboo workers are well placed in their native places like textile printers in Bagh; weavers in Mahaeshwar, they have their own settlement pattern as per their trade. When they come to a city in search of employment they have to adopt a new trade or either continues with their own. There cultural identities are well defined in the traditional settlements in their built forms, decorations and lifestyle. The settlement of Bhil or Gond tribe can be easily identified through these identities.

Figure 7 Tribal house

Figure 8 Bamboo workers

Figure 9 Gond painting

TRANSITION FROM RURAL TO URBAN

In Bhopal there is a planned urban settlement BHEL, a township developed for the workers. The planning of the settlement is done on the basis of economic status of the workers from one bedroom unit to four bedrooms unit. The township is designed with facilities like schools, colleges, sports complex, market places and other amenities. The spaces are provided for their religious and community activities although a township developed for the secular and democratic society as per Nehru's vision. There is no such defined culture or identify of the settlement. It has a concept of global village which has a similar character of any other planned city of India. The cultural identities are vanishing from the modern cities. In the urban planning there is no place for traditional settlements and vernacular patterns. Parallel to this industrial development there are also traditional crafts and trades which are integral part of the society, for example a refrigerator could not replace an earthen pot in an Indian house. When a pot is brought in the house, a ritual is performed to fill the water. This shows that the potter is an integral part of the society and the tradition continues in this manner.

METHODOLOGY

The vernacular and urban dwellings are documented and analyzed on different parameters of culture and architecture. The dwellings of Potters and Bamboo workers are selected from vernacular and urban settlements. The dwellings of workers from BHEL Township, Bhopal are selected from an urban settlement. The parameters of changes in culture are characteristics, aesthetics, planning and community living. The parameters of changes in architecture are site planning, response to climate, material, construction method & techniques and cost effectiveness.

VERNACULAR SETTLEMENT OF POTTERS (KUMAHAR)

Potters community lives in separate clusters in village settlement due to their work culture. A traditionl dwelling of potters at Damnod, District Dhar, Madhya Pradesh is selected for a case study. In the dwelling the spaces are required for storage of raw material and finished products, preparation of clay, creation of pots, roof tiles or bricks and firing. In the front there is an open space for working and selling and on the backyard for private space like washing, bathing and other household works. The enclosed spaces are used for sleeping, cooking and living. The toilets are not attached with the dwelling. A separate room for donkey is provided. These communities are associated with ceremonies of birth, marriage and death. The three to four generations live together which forms a strong social binding. The walls are constructed by rammed earth or brick masonry with mud mortar. The brick piers or wooden post are the vertical structural members. The attic is made of bamboo matting with mud mortar or wooden planks and is used as storage space. The stone slabs are rarely used because of site conditions. The roof consists of rafters, purlin with the covering of country tiles. The decorative figures of bird or animal are placed at the ridge. The tiles are moulded and casted or made on potter's wheel. The plastering is done by mud plaster, red clay, white clay and yellow ochre. The flooring has rammed earth covered with cow dung. The wooden door and windows are double leaf. The niches are used for storage.

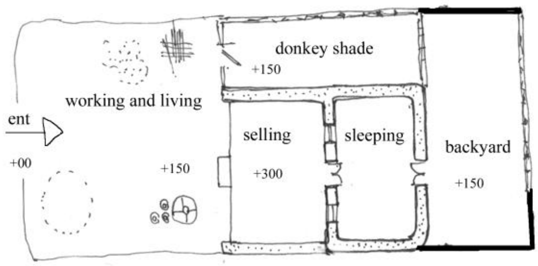

Figure 10 Plan

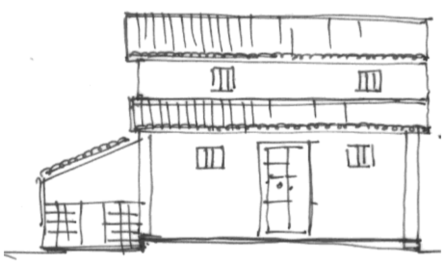

Figure 11 Elevation

When they migrate to cities, they do not have space to settle down as per the work culture. Therefore, they are forced to live on the "eyeshores", 'Jhuggis' or on the pavements. In the planned residential zones, the firing is not allowed where such living and working can be performed together.

The potter's community residing on the pavements of Link Road No.3 in Bhopal is documented. There is a planning proposal for resettlement for these dwellers under JNNURM, which is a multistoried housing in the same locality. In the new dwellings they cannot live and work per their work culture. If they are not given an opportunity to work, they are forced to switch over to another trade. As a result this craft will slowly vanish from the society.

Figure 12 Roadside settlement

Figure 13 Living space

Figure 14 Working space

Figure 15 Selling space

Figure 16 Interacting space

Figure 17 By new settlement

VERNACULAR SETTLEMENT OF BAMBOO WORKERS (BASOR)

Bamboo workers community lives close to the forest. The Basods are the people belonging to community of bamboo craftsmen who are traditionally dependent on bamboo for their livelihood. They are mostly engaged in construction work like scaffolding or temporary structures. Variety utility items are made like furniture, basket, ornaments, musical instruments, effigies, totems etc. A traditionl dwelling of bamboo worker at Churhat, District Satna, Madhya Pradesh is selected for a case study. They have living and sleeping spaces along the courtyard and the working space is outside the courtyard in front of the dwelling. The courtyard is used for household works, storage space for raw material and a pig house adjacent to the dwelling. This community is also closely associated with the society, when a girl is married; the essential utility items are given to her in a basket called 'pitara' or 'dori'. It is very auspicious. The walls are made of thick bamboo matt covered with mud plaster, thick bamboos are used for vertical support. The attic floor is made of bamboo mating, covered with mud plaster. The roof consists of wooden trusses, rafters and purlins of bamboo and covering of country tile or thatch. The mud is used for plastering; flooring is done by rammed earth, covered with cow dung. The timber doors and window frames with bamboo shutters, bamboo jail used for lighting and ventilation.

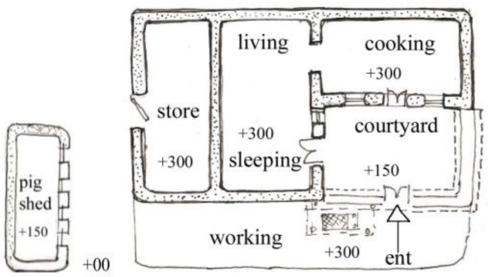

Figure 18 Plan

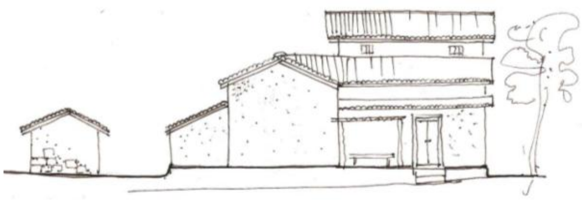

Figure 19 Elevation

This community is residing on the pavements of Link Road No.2 in Bhopal. In the similar way, for resettlement for these dwellers under JNNURM, a multistoried housing is provided in same locality, which is not as per their work culture and will result in vanishing of the craft from the society.


Figure 20 Roadside settlement


Figure 21 Living space


Figure 22 Working space


Figure 23 Selling space


Figure 24 Interacting space


Figure 25 By new settlement

These communities have a tendency to calls his family members or relatives when one gets an employment in the city. They start living in close vicinity; form a community, quite similar to the village pattern. This result in the formation of basti's (informal settlement) like potters basti, basoor basti, lohar basti etc. and are named after their trade. They face hardship in daily life; their biggest strength is social binding. Similarly the construction labors also form basti, named after their state as Chhattisgarhi basti, Orriya basti etc. There lives are challenging; even a birth or a death can take place at the site. Sometimes they come across serious incidences like Gas tragedy, Bhopal in 1984, the residents of Orriya basti were among the victims. It was one of the biggest industrial disasters; lakhs of people lost their life.

URBAN SETTLEMENT IN BHEL TOWNSHIP, BHOPAL

This township has been designed for an organized sector for industrial workers with modern amenities and facilities. It is a RCC framed structure, use of modern materials and construction techniques, technical experts, skilled labor were the prime concern. There is monotony in form and character which has similarity with any other planned urban settlement in India. The dwellings are designed as per the economic status of the worker. There is not a defined character and does not reflect a particular culture. Hence there is a change in living pattern and lifestyle.We have selected two type of dwelling units of the township, Type A and Type C. Type A is one bedroom unit with living room, kitchen, verandah, courtyard with bath and wc with an area of 454 sq ft. Type C two bedroom unit with two verandahs, kitchen, one common toilet and one attach toilet with an area of 883 sq ft.

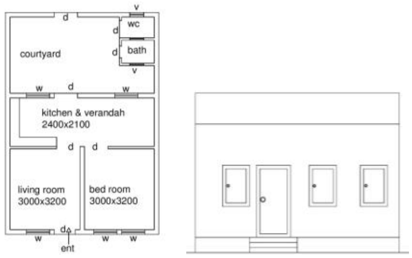

Figure 26 Plan and Elevation of 'Type A'

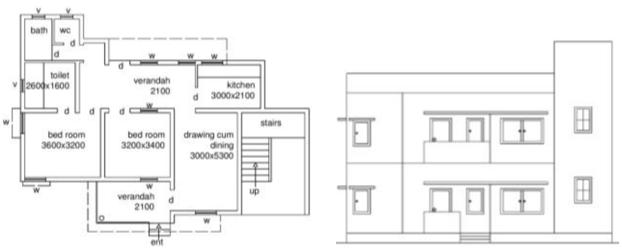

Figure 27 Plan and Elevation of 'Type C'

ANALYSIS

Table 1. Parameters of Changes in Culture and Architecture

Parameters of changes	**Details**	**Vernacular Architecture**
Culture	Characteristics	Different cultures of tribal and folk are well defined.
	Aesthetics	Murals, painting, sculpture are integral part of architecture.
	Planning	Settlement planning as per their lifestyle like circular, squatter and linear.
	Community living	Choupal, otla, chowk, courtyard for social interaction. Strong social binding.
Architecture	Site planning	Planning as done as per topography and landscape.
	Response to climate	Plan form and built form are evolved as per the climatic conditions of the region.
	Materials	Locally available material like stone, mud, bamboo, timber and lime are used.
	Stone	It is used in masonry, roof, flooring, in-built furniture, Chajjas and Jharakhos are provided for shading.
	Mud	Rammed earth, adobe, mud mortar used in random rubble masonry, helps in acoustics and heat resistant.
	Bamboo	Because of strength and flexibility widely used as structural skeleton, roofing structure, composite construction and utility items like jaails, baskets etc.
	Timber	Used as a structural component, in the construction of beams, rafter, trusses, doors, windows and furniture.
	Lime	Used in brick masonry as a binding material, for plastering and fresco painting.
	Brick and Terracotta	Brick is used for masonry walls, piers, jaalis, etc. Terracotta is used in roofing tiles, roof gutters, pottery.
	New materials	Adaptability to new material.
	Cost-effective	Because of locally available material, saves the cost of transportation
Parameters of changes	**Details**	**Modern Architecture**
Culture	Characteristics	Universal characteristics, no reflection of local culture
	Aesthetics	Contemporary art is depicted.
	Planning	People live in isolation, less interaction with others, no place for local arts and crafts.
	Community living	Cultural hubs, sports complex are interaction spaces, intimate relationship and social binding is less.
Architecture	Site planning	Planning is as per the economic status of the user like HIG, MIG, LIG and EWS.
	Response to climate	Eco-friendly materials are in market but are expensive.
	Materials	The market ones are given priority than local ones.
	Stone	With modern techniques it’s used in a better way.
	Mud	Rammed earth, adobe are used in modern design.
	Bamboo	It is used as a new material in modern construction.
	Timber	Used for doors, windows and not as structural member
	Lime	It is rarely used, limited to conservation
	Brick and Terracotta	Brick is used for masonry walls, piers, jaalis, etc. Terracotta is used in roofing tiles, roof gutters, pottery.
	New materials	Adaptability to new materials is more
	Cost-effective	Material and transportation cost are high.

Source: Author

RESULTS AND FINDINGS

The vernacular dwellings have a special character that the spaces are multifunctional and each craft requires a different pattern of spaces. The dwellings are designed by keeping in mind the future expansion. The form of a building is evolved from its functions. Architectural characteristics are defined by their work culture. Pottery is a traditional craft which transfers from one generation to another. So it is continuously expanding as per their requirements hardly any change is seen in the living pattern and lifestyle. Some of the potters migrate to city for employment. Thus, migration is a major problem of urban settlement. The planned housing is defined by the economic status of the user. The modern material are used which are changing with new construction methods and techniques. In vernacular there is a subtle change in material and character. The acceptability of new material and technique is less. Therefore, they have a specific character and lifestyle. In urban settlements the changes are easily noticeable; acceptability to new material and techniques is high. A new character is coming up which has no relevance with the vernacular, it has a global character. The data collection and observations there is no space provided in the urban planning for traditional craft like potters, bamboo workers, blacksmith and weavers etc. which are an integral part of the society. Hence in the urban planning the provisions for these settlements should be provided. The research can give vision to policy makers, planner, architects to look into the traditional crafts and trades, understanding the vernacular traditions and incorporating them in the contemporary planning. The impact of globalization has threatened traditional and cultural values by the forces of economic, cultural and architectural homogenization. This has brought disregard for traditional environment and often considered as a symbol of poverty and backwardness. In the race of modernity, values, beliefs, culture are removed from the society. The steps towards sustainable cities are taken at various level such as Earth Summit, Agenda 21 at the international, JNNURM at national and other inititaves include National Habitat Mission, National Action Plan for Climate Change, Water Mission, Energy Efficiency Mission and so on. (Tipnis, 2012)

INTEGRATION OF VERNACULAR AND MODERN IN THE CONTEMPORARY DESIGN

Vernacular traditions lead a way towards the sustainable built environment. The valuable lessons from vernacular can be integrated with the modern to produce sustainable designs. Vernacular traditions can also be used as a design tool for slum re-developments. The designing of these settlements need understanding users' way of life, social and cultural values. LIC housing by Charles Correa, Anandgram by Kamath Design Studio in India are few examples of integration of vernacular and modern. Architects like Louis Kahn, Lourie Baker, B.V. Doshi, Shirish Beri, Revathi and Vasanth Kamath, Satprem Maini have incorporated the principles of vernacular traditions in their contemporary buildings (Tipnis, 2012).

Anandgram in Shadipur, Delhi is selected as an example of resettlement. It is designed by Kamath Design Studio, Delhi, India in 1983. Architect Revathi and Vasanth Kamath their work is a creative synthesis of attitudes and technologies into an aesthetic habitat and a way of life. They believe in using natural resources and utilize them to the most and are on a mission to substitute concrete, cement and energy-consuming systems with sun, water, wind and soil. Ecology must be understood to encompass both nature and culture (kamathdesign.org). The settlement is designed for traditional community of performing artists and craftsmen in their own traditional pattern by integrating values, customs, rituals, beliefs and lifestyle. The challenge was to provide the built-fabric in relation to the urban form. It is one of the best examples of reflection of culture in architecture in the contemporary design.

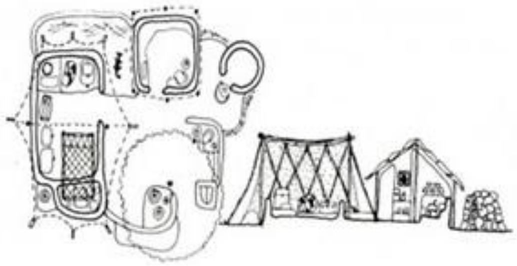

Figure 28 The change in unit after 30 years

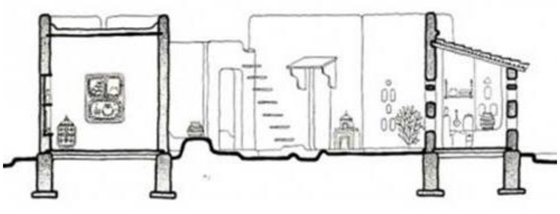

Figure 29 The setion through a cluster

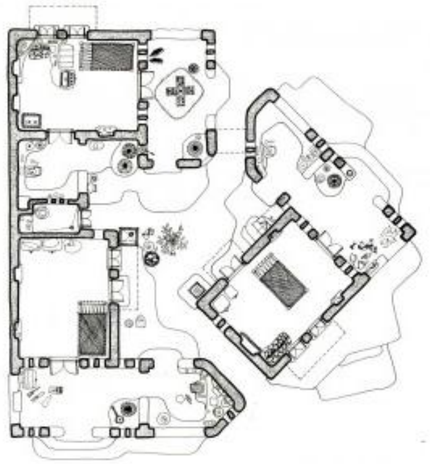

Figure 30 The detailed plan of a cluster **Figure 31** The resettlement plan

CONCLUSION

The changes in culture and architecture are reciprocal. The impact of one is reflected on the other. India’s rich cultural heritage is vanishing due to the influence of urbanization and globalization. In order to protect and conserve our rich cultural and architectural heritage the elements of vernacular should be incorporated in the contemporary planning and architecture. The provision should be made to incorporate vernacular architecture and traditional knowledge in the policies. The policy makers, planners and architects should consider this in their work for betterment of society. The paper concludes by learning and appreciating the principles of vernacular architecture and integrating them with the contemporary knowledge and technology.

“Quality of life is enhanced through good architectural design which responds to the needs and wishes of users and use of natural materials and good urban design which allows creation of green spaces and reduction of noise and pollution.” Birkauser, (Tipnis, 2012).

ACKNOWLEDGMENTS

We are greatly thankful to Department of Culture, Archeology, Tribal Research Institute, Tribal Museum and State Archeological Museum of Madhya Pradesh.

GLOSSARY

Chaupal: denotes a common meeting place in a village which is owned by the community.
Bhil: one of the main tribes lining in the Jhabua and Dhar region.
Dwelling: is the name given to a house form or for living somewhere.
Jaali: lattices made of bamboo, grass and clay, used on mud houses in Sarguja, Raigarh.
Pithora: votive wall painting made by the Bhils, worshipped with sacrifices.
Sahariya: primitive tribe living in Gwalior, Shivpuri and Morena in the north-westrn part of Madhya Pradesh. The people of this tribe consider Sabari of Ramayana to their first ancestor.

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http://www.kamathdesign.org/project/anandgram

Vernacular Ecology: Environmental Recreation of Ancient Dwellings in Southeastern Turkey

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ABSTRACT

"At the beginning of the 21st century, in a time of rapid ecological degradation, globalization and destruction of much vernacular architectural heritage, concerns for the maintenance of the local, cultural identities, and an awareness of the need to provide sustainable built environments are set to raise an interest in the vernacular traditions" (Asquith & Vellinga, 2006) for a culturally-embedded environmental design future. This paper investigates the Southeastern Turkey's vernacular architecture with the aim to partake in the development of a New Hasankeyf proposal by investigating design guidelines for the new dwellings of the future city. The basis of the explored guidelines relies on the concept of 'recreating the vernacular' with the primary goal to enhance the environmental performance of the proposed dwellings; through passive means and without compromising the cultural/geographical premonitions that it originally derived from by implementing 1) compact form, 2) adapted space layout and 3) improved building elements.

INTRODUCTION

In an era, in which archeological sites are preserved with utmost diligence, Hasankeyf - a declared conservation area in Southeastern Turkey - is left at its destiny, which would be determined by the Turkish Government that attempts to flood the region with its Ilisu Dam along Tigris River as a part of an "integrated irrigation and agricultural project" (Demirbilek, 1997) called GAP.

It is not only the inconceivable truth of inundating such an ancient city which results in a homeless population and ever lost heritage, but also the insensibility of the government's new construction proposal set forth that both encourage a need to offer construction and design guidance for a sustainable, long-lasting, culturally-familiar and aesthetically-amalgamated design approach.

Over the last century, the region has faced a "rapid and uncared growth" as observed by (Demirbilek, 1997) due to fast population increase, changes in the social context and economic restrictions. This has encouraged an incongruous, fast-pace construction without any considerations for (cultural) modern era notions. The main goal of the current research is, therefore, to understand and explore the limitations of the vernacular sustainable strategies in Hasankeyf and learn how the local approaches could be implemented in and further adapted to a new development within the region. Considering this, the paper at this stage, adamantly envisions the 'recreation of the vernacular' as an integral aspect of long-term sustainability by investigating potential passive measures, which could provide annual occupant comfort.

The recreation of the vernacular concentrates on exploring a design of mostly self-sustaining dwellings embedded within an environmentally-responsive enclosure without compromising elements that define the region's unique architecture but enabling it to adapt to the contemporary family needs.

REGIONAL INFLUENCES

Climate & Topography

Hasankeyf is a hillside settlement with an altitude reaching up to 495m perched within a valley in the hot and dry Southeastern region of Turkey. The great temperature difference of about 32°C between the hot summer and relatively cold winter months made it "imperative to adopt to the natural forces from the early days" of the region's history (Alioglu, 2000).

The climate analysis of the closest city of Batman obtained from the climate software, Meteonorm indicates that the area faces two annual extremes with a minimal amount of rainfall and a good amount of global radiation: fairly hot summers and cold winters with a large diurnal temperature difference. Based on this climate analysis, two different comfort bands can be determined by following de Dear's formula calculations as outlined by (Szokolay, 2004): the resulting comfort band for summer ranges between 24°C and 29°C, and for winter, the band falls between the temperature range of 17°C and 22°C.

Culture & Architecture

The historical perspective reveals that in the vernacular architecture of Anatolia, human beings built dwellings based on a specific region's geographic and climatic provisions along with the religious premonition of orienting the main façade towards Qibla - to Mecca, which is the direction of the Holy Land of Islam (Demirbilek, 1997).

Hasankeyf is an exceptional precedent to such a hypothesis: the city's settlement on hillside topography with introverted house layouts, not only accentuates the region's cultural privacy, but also represents the environmental benefits such a settlement and layout provide (Demirbilek, 1997). Moreover, the formation of semi-open (Eyvan & Revak) and open (courtyard & terrace) spaces along with enclosed areas forming the typical 2-level construction, differentiation of rooms for solely male and female occupancy, and small openings to outside mimic the characteristics of the area's closed-in lifestyle (Alioglu, 2000).

The region houses three building typologies: the U-type (- most commonly encountered within the vernacular city fabric), the L-type and the Linear Type. The building forms portray the family status and size, ranging from the most prestigious house with the largest family in the U-type to medium size in the L-type and to the smallest building form of the Linear Type. Despite the difference in their size and form, all the building typologies have traditional flat roofs, same treatment of architectural features and closely related program allocation and space layouts.

CASE STUDY FIELDWORK & ANALYTIC STUDIES

A fieldwork is conducted and measurements are taken in a precedent dwelling - the Gozuoglu House - in Mardin (- a nearby city to Hasankeyf) with the aim to investigate the vernacular building's performance.

The prestigious Gozuoglu House represents region's emblematic, architectural features within its 2-level construction of 90cm-thick, non-insulated, locally-sourced stone walls with single-glazed, small windows and a U-type layout of varied open, semi-open and enclosed spaces.

The house consists of 'living units' as described by (Alioglu, 2000) which include bedroom areas (within Haremlik and Selamlik living rooms) and the most esteemed men (Selamlik) and women (Haremlik) living rooms at the upper level. These spaces are commonly occupied during the summer season due to their high volume with ceilings reaching up to 5m (Demirbilek, 1997). The external shutters supplement indoor comfort within these spaces by providing protection against (direct) sunlight during the peak hours of the day.

The winter season targeted lower level, on the other hand, embraces daily 'service areas' (Alioglu, 2000) including an office (live/work room) and a study room along with a kitchen across a storage space, and an earth-dug room, which is most commonly used during the summer season as it stabilizes the indoor temperature and maintains the space cooler.

Fieldwork

The fieldwork of the Gozuoglu House is completed using Tiny Tag data loggers (for room dry-bulb temperature) on the sunny days of 4th - 6th of July 2011, during which the average outdoor temperature ranged between 30.1°C and 31.2°C. The intent of the fieldwork is to understand the temperature performance of two similar spaces at different levels based on solar radiation impact. A living room - Haremlik and a live/work room - the office space are chosen due to their comparable layout and size (28m^2 of floor area in Haremlik and 25m^2 in the office) along with analogous window-to-floor ratios (13% in Haremlik and 11% in the office), occupancy pattern and ventilation rates. (Note: Both spaces were not occupied during the fieldwork period).

The obtained data logger results indicate that thermal mass maintains both spaces' internal air temperatures at a fairly stable level (with a 2°C fluctuation) throughout the day despite the large 20°C diurnal fluctuation of the external temperature **as seen on Figure 1**.

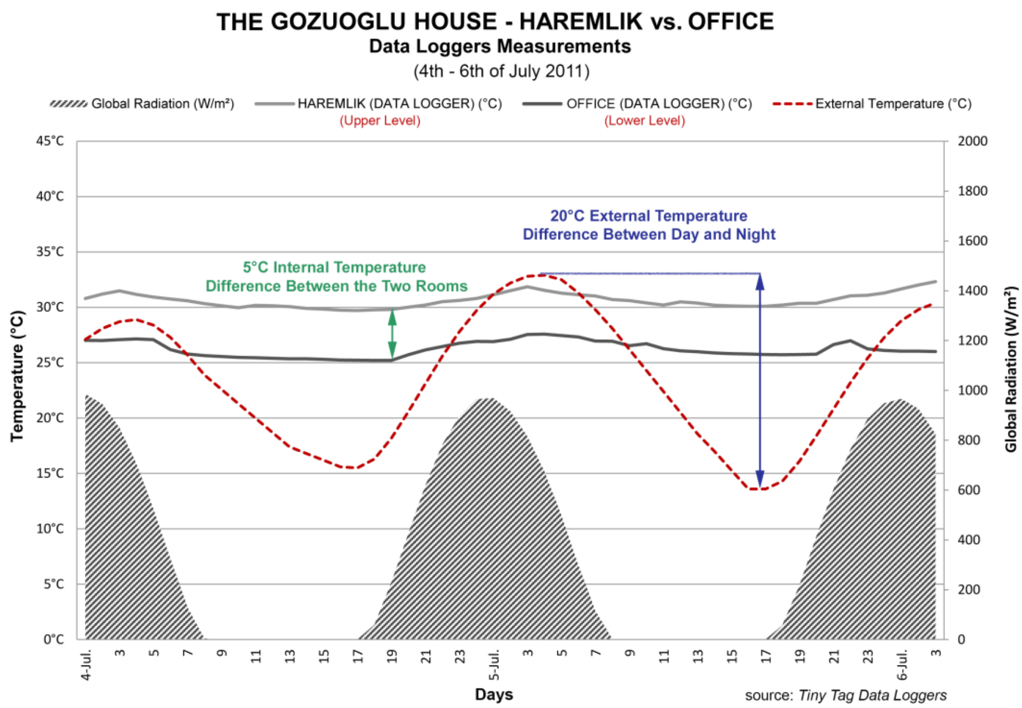


Figure 1   Fieldwork measurements' graph of two rooms in the vernacular Gozuoglu House

The 5°C internal air temperature difference between the upper level Haremlik and the lower level office highlights that solar radiation potentially plays an influential role in the increase of the internal air temperatures - a theory that needs to be confirmed by the subsequent analytic studies: the unobstructed Haremlik's east and south facing windows increase solar access, whereas the lower level office's only east facing, overshadowed (by terrace above) windows limit it.

Hypotheses

Analyzing the climatic characteristics of the city including S-SW wind flow pattern and high solar angles along with observing the case study fieldwork results, a series of strategies are formulated based on initial environmental hypotheses, which focus on passively improving the indoor comfort within such a vernacular enclosure:

- Increase of solar access into spaces
- Compact spaces of airtight, thermal mass construction
- Shading elements
- Night time ventilation (with additionally openable, upper pane windows and/or skylights)
- Maintenance of the vernacular's semi-open and open spaces that further contribute to the indoor

comfort enhancement: during winter, these spaces provide buffer from the cold outdoor temperature while during summer, they offer a shaded microclimate environment (Fathy, 1986; Koch-Nielsen, 2002), extending the daily family life.

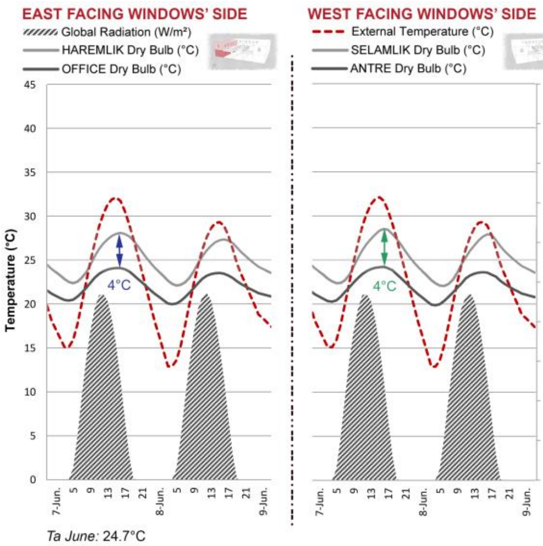
Analytic Studies

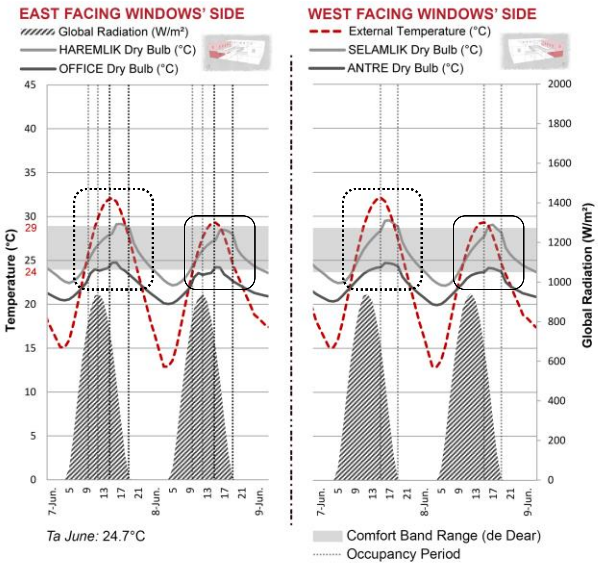
At the conclusion of the obtained fieldwork, analytic studies are conducted using Thermal Analysis Software (TAS) for calibration, understanding of the dwelling's annual performance and confirmation of the proposed strategies in relation to the formulated environmental hypotheses.

The created base case model complies with the vernacular case study precedent in terms of building form, layout and inputs. The completed TAS model is examined for building's performance of levels, orientation, solar radiation access and internal heat gains throughout a typical summer (7th - 13th of June) and a winter week (1st - 7th of December). The analysis and comparison of each simulation are evaluated against the comfort bands (24°C - 29°C for summer and 17°C - 22°C for winter) calculated according to de Dear's formula.

Four rooms are selected for the simulations: Haremlik (the upper level living room with south and east facing windows), Selamlik (another upper level living room with south and west facing windows), office (the lower level live/work space with east facing windows) and Antre (a lower level living room with west facing windows). Both of the lower level rooms as well as the upper level ones are given the same window-to-floor ratios of the vernacular (13% on the upper level and 11% on the lower level) to minimize the parameters that would influence the outcome.

Similar to the fieldwork measurements, the summer simulation results for both orientations indicate that solar radiation has a valid influence on increasing spaces' internal air temperatures: the more exposed upper level portrays approximately 4°C warmer temperatures (before the internal heat gains are applied) compared to the lower level rooms **as indicated on Figure 2**.





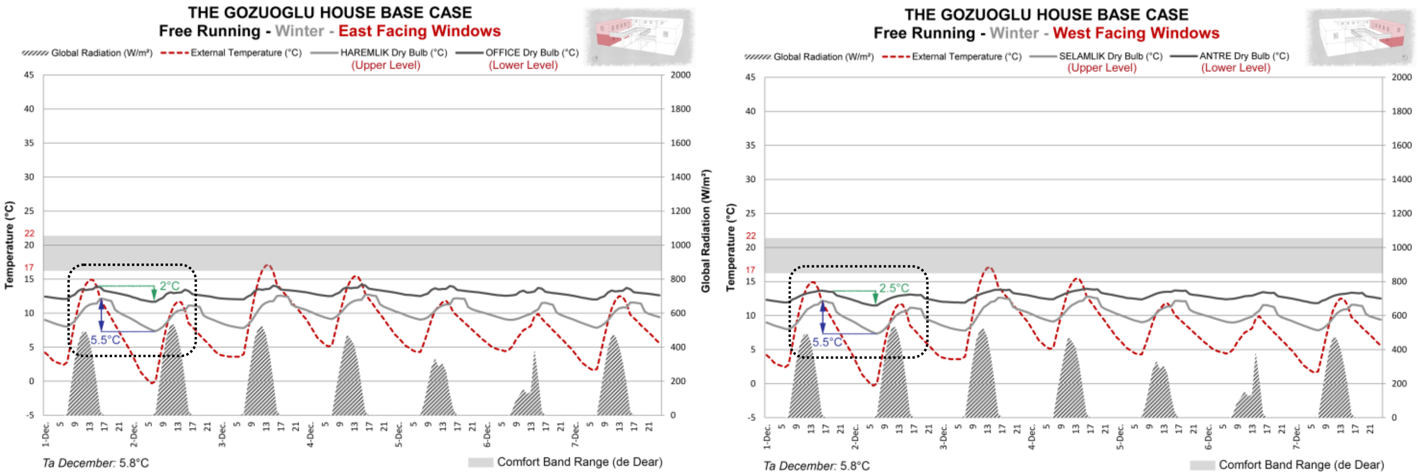
Infiltration: 1ach
Ventilation: **Haremlik:** 0.6ach, **Office:** 0.3ach, **Selamlik:** 0.6ach, **Antre:** 1.4ach

Figure 2 The east and the west facing summer temperature graphs of the free-running Gozuoglu House Base Case simulations – Influence of solar radiation

Figure 3 The east and the west facing summer temperature graphs of the Gozuoglu House Base Case simulations – Influence of internal heat gains (all source: TAS)

Despite the impact of solar radiation, the influence of orientation (East vs. West) is minimally observed due to the U-type building form that overshadows itself: two same level rooms portray a fairly close temperature range. Nonetheless, it can be clearly identified that the impact of internal heat gains is the most direct: the temperatures of both levels initially increase following the external temperature pattern, however, with a time-lag due to the dwelling's heavy-mass construction. Once the internal heat gains (i.e. mainly occupancy and some lighting) are applied into these spaces, the internal temperatures reach their peak approximately at a 1°C - 2°C higher level **as highlighted with on Figure 3**. When the internal heat gains are removed as spaces become unoccupied, the internal temperatures decrease following the pattern of the external temperature. Nevertheless, the internal temperature levels do not necessarily mimic the external temperature drop if the internal heat gains are continuously applied within these spaces **as highlighted with on Figure 3**.

Reassuring the previously formulated hypotheses, the free-running (without heating or cooling) Gozuoglu House Base Case exhibits a much poorer performance during the cold winter season with internal temperature levels falling below the calculated comfort band of 17°C - 22°C, following a fluctuation line of 7°C - 14°C **as highlighted on Figure 4 (a) and (b)**.



Infiltration: 1ach
Ventilation: Haremlik: 0.6ach, **Office:** 0.3ach

(a) The western wing temperature graph

Infiltration: 1ach
Ventilation: Selamlik: 0.6ach, **Antre:** 1.4ach

(b) The eastern wing temperature graph

Figure 4 (a) The western wing and (b) the eastern wing winter temperature graphs of the free-running Gozuoglu House Base Case simulations (source: TAS)

Moreover, the winter season simulations highlight the better performance of the lower level spaces (- the office to the West and Antre to the East) due to their less exposure to the interchanging outdoor temperature. Following this line of thought, it is not only the higher volume of the upper level with taller ceilings and a larger window-to-floor ratio, but also the exposed surfaces further contribute to the heat losses that occur at this level, in return diminishing its performance.

Critical Review

The conducted fieldwork and current analytic studies confirm the initially formulated environmental performance hypotheses for the investigated vernacular dwelling, in which the heavy-mass stone construction and small window-to-floor ratio maintain the internal temperature levels stable during both winter and summer months, however, passively achieving indoor occupant comfort during the hot summer period, but not providing it for the cold winter season. Considering this, the focus of the future analytic studies in this paper is to enhance the vernacular building's performance during winter while reducing the Annual Heating Load Demand and maintaining the summer indoor comfort.

Following the pattern of the previous section, a new hypothesis is formulated stating that the building scale manipulations such as improving the construction (i.e. implementing double-glazing and insulation) and increasing window-to-floor ratio along with defining a layout that is proportionate to the targeted occupants (in terms of floor area for the resulting internal heat gains) would increase the building's performance during the winter season while also maintaining the desired summer comfort.

PROPOSAL & ANALYTIC STUDIES

Vernacular dwellings of the region (especially the U-type building form) were meant for large families because traditionally married males never left their family home (Alioglu, 2000). Nonetheless, current married generation prefers to privatize their individual, core family life from the extended relatives. Considering this, guidelines are presented for the 'recreation of the 'modern' vernacular' with the New Hasankeyf Base Case being created following the reiterated parameters:

- Compact dwelling size proportionate to a single family of 4 people, which corresponds to the Linear Type encountered within the vernacular fabric (Note: Per the previously completed analytic studies, the U-type building depicts the worst performance among all the typologies due to its form, which limits solar access and enables heat loss via large amount of exposed surface area. It is also due to this reason that the Linear Type is chosen to represent a new dwelling prototype for the future city of Hasankeyf).
- Reduced stone wall thickness from 90cm to 30cm for ease of transport, labor and cost reduction
- Adequate space layout to accommodate the modern era adaptation of programs (i.e. identification of programs for the vernacular model). (Note: Separate bedroom and bathroom spaces were not a part of the vernacular dwelling layout; instead they were a part of a 'shared space' system. However, with the increasing need of individual privacy within a dwelling, the locals of the region are encouraged to redefine some rooms to provide for the needs of those 'unidentified' programs. This 'forced' process often takes away from the function and the proposed layout of another vernacular space in the building, posing contradiction to the traditional occupancy pattern and space layout).

The created New Hasankeyf Base Case has the input values **as shown on Figure 5**, deriving from the region's precedent characteristics.

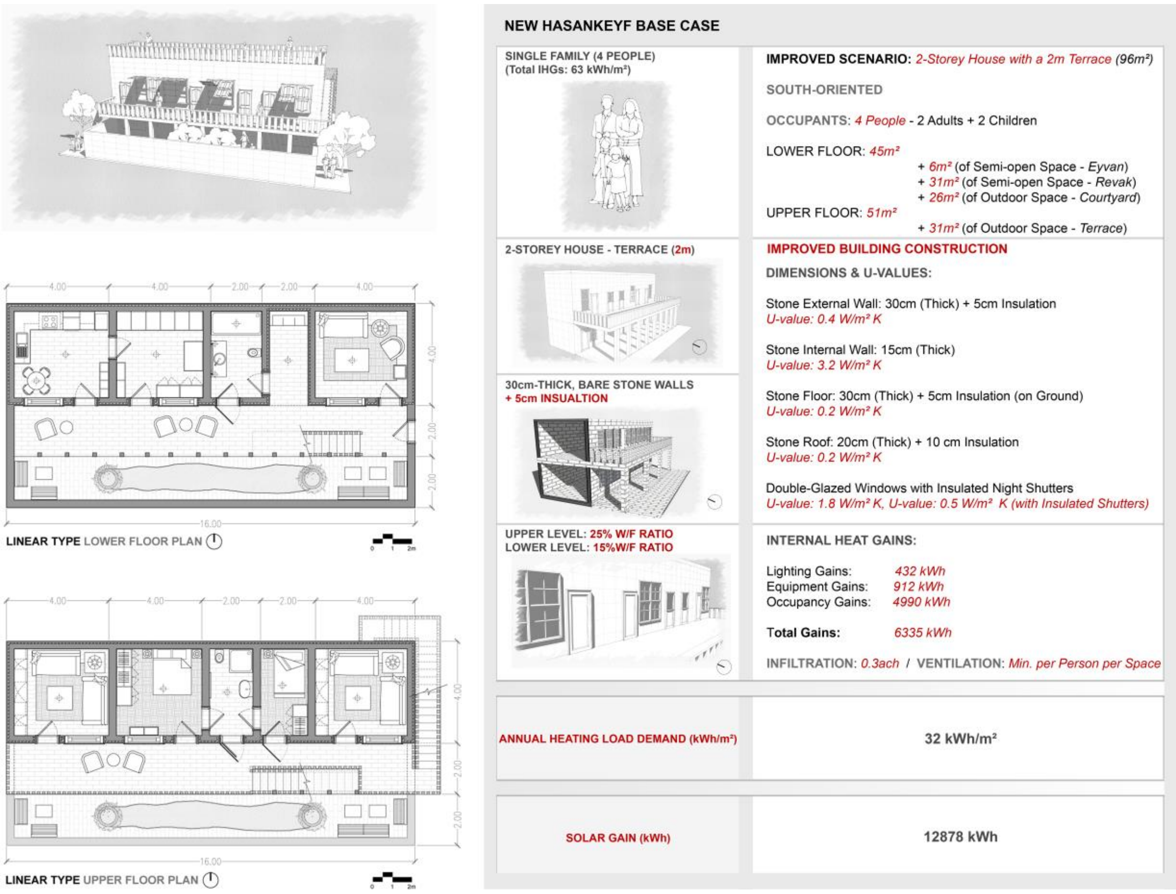


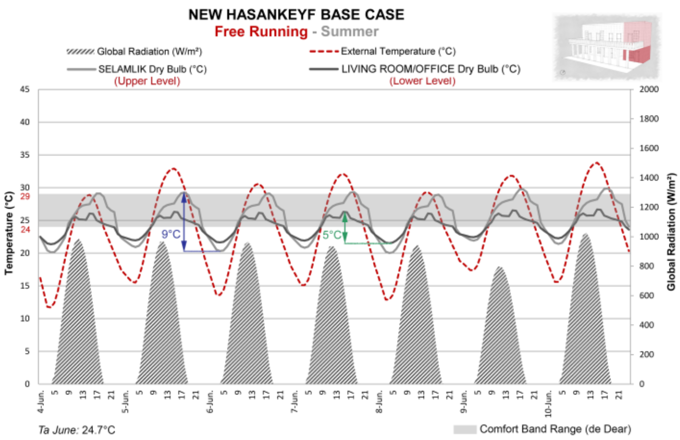
Figure 5 The New Hasankeyf Base Case diagrammatic drawings and analytic model inputs (source: TAS)

The New Hasankeyf Base Case's simulations conducted using TAS restate the previously encountered outcome: the model exhibits a good performance during the summer period with temperature patterns (for both levels) falling within the target comfort band, whereas it suffers throughout the cold winter season. As hypothesized earlier, the following building scale manipulations are additionally considered for the enhancement of the proposed dwelling's annual performance:

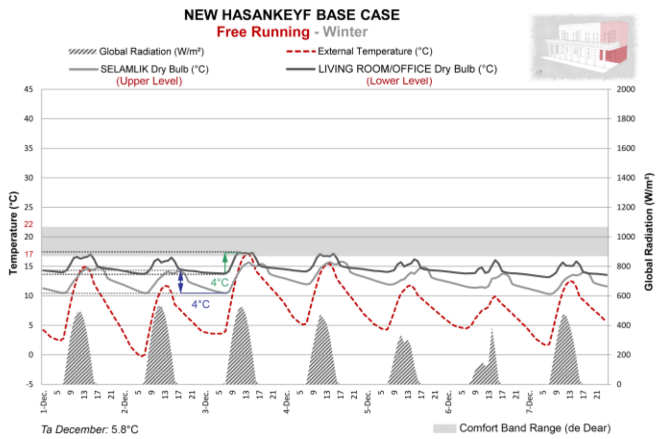
- Addition of insulation along the exterior of structure (from the vernacular none to 5cm thickness)
- Change of glazing type (from the vernacular single to double-glazing)
- Increase of window-to-floor ratio (from the vernacular 11% (at lower level) and 13% (at upper level) to 15% (at lower level) and 25% (at upper level) both with insulated, external shutters)
- Reduction of terrace depth (from the vernacular 4m to 2m depth)

A architectural approach combining the considered parameters along with an optimum South (Qibla) orientation has been established based on a balance of Annual Heating Demand reduction and increase of Solar Gain, and it is reflected within the design prototype for the New Hasankeyf dwellings. To quantify the proposed prototype's performance, a set of a typical summer and a winter week simulations has been completed comparing an upper level living room (Selamlik) to a lower level one (living room/office). The obtained summer simulation results of the free-running (without heating or cooling) New Hasankeyf Base Case **as seen on Figure 6 (a)**, indicate a stable profile for the lower level living room/office, whereas it portrays a bigger fluctuation pattern for the upper level Selamlik due to increased ventilation strategy applied in order to maintain the internal temperature levels within the set comfort band with newly increased window-to-floor ratio.

The New Hasankeyf Base Case's internal temperature profiles portray significant improvements of approximately 20-25% for the winter model performance when compared to the vernacular Gozuoglu House Base Case: both the upper level Selamlik and the lower level living room/office display a more regulated temperature pattern with a daily fluctuation reaching up to 4°C **as indicated on Figure 6 (b)**. The obtained results highlight both levels' potential for achieving comfort range with increased occupancy and/or minimal heating input: it has been observed that when there is constant solar radiation above 500 W/m^2 and the external temperature exceeds 10°C, the lower band of the comfort zone can be achieved during the occupation hours under free-running conditions. Moreover, there is an evident improvement in the lower level space's internal temperature levels from the Gozuoglu House Base Case condition. The improvement also applies to the upper level Selamlik's internal performance with a 3°C higher temperature range compared to the vernacular Gozuoglu House Base Case model. Considering this, the band in which the heating system would operate in order to reach the comfort range would be much smaller and therefore, significant savings can be achieved.



Infiltration: 0.3ach
Ventilation: **Selamlik:** 6ach, **L.R./Office:** 2ach



Infiltration: 0.3ach
Ventilation: **Selamlik:** 0.9ach (min.), **L.R./Office:** 0.7ach

(a) The summer temperature graph

(b) The winter temperature graph

Figure 6 (a) The summer temperature graph and (b) the winter temperature graph of the free-running New Hasankeyf Base Case simulations (source: TAS)

Despite the prototype dwelling passively not achieving a complete annual range within the calculated comfort bands, the proposed guidelines relay an achieved summer comfort and an enhanced winter performance without compromising the origins of the vernacular's architectural existence: the primary focus of the research is to offer guidelines to design for inhabitants who are devoted to meticulously preserve their cultural traditions mirrored onto the region's architecture and lifestyle.

The conducted research of the previously formulated hypotheses via supplementary analytic studies in this section, reassures the set theory in regards to the 'recreated' vernacular dwellings' performance. More importantly, this research leads to an outcome that can provide guidelines for the New Hasankeyf dwellings' passive design approach, through which not only current, but also future builders, designer and occupants can dwell upon, learn and grow, carrying on the precedents. The primary scope of this study has been to investigate the limits of the localized vernacular passive measures in order to enhance the environmental performance of dwellings within the Hasankeyf area. Nonetheless, further studies that are based on alternative performance metrics would explore useful measures that not only 'recreate', but also assist in achieving a more efficient and improved sustainable design by 'redeveloping' the vernacular lessons learned in this initial research.

ARCHITECTURAL DESIGN

The New Hasankeyf proposal derives from the architectural syntax of the vernacular, which is based on a 4mx4m grid layout (Ozbek, 2004). It represents housing units that achieve desirable indoor living conditions throughout varied seasons. The premise of the units' design lies on maintaining the vernacular language based not only on its space layout, usage and building form, prolonging the roots of the cultural lifestyle and traditions, but also on its architectural aesthetic that smoothly amalgamates with the existing surrounding.

In addition to preserving the vernacular's space layout and function, the bathroom and the bedroom spaces are compensated in the new proposal, all with either standard or high-level windows. Reiterating the transitional spaces, the New Hasankeyf proposal consists of terraces forming Revaks (semi-open spaces) below, which lead to a sheltered, private courtyard, in which comfort is enhanced with water elements and vegetation.

The varied façade treatment evident in materiality, scale and ornament application along with diverse opening sizes (15% on the lower level and 25% on the upper level) and ceiling heights (2.5m at the lower level and 5m at the upper level) visually contribute to the seasonally desired transition of the two levels: the linear patterned, local wood finish with smaller windows encapsulated with minimal, insulated, wood shutters on the lower level reflects the simplicity of the 'service areas' it encloses behind; whereas the elegant, local stone arrangement and the larger windows with ornate, insulated, wood shutters highlight the prestigious 'living areas' of the upper level.

The beneficial reconsideration from the vernacular example in the New Hasankeyf prototype is the secure extension of family life onto the flat rooftop enabled by the elaborate railing design, which, in addition to the terrace's, defines the perforated, horizontal framing of the building's overall façade.

CONCLUSION

The New Hasankeyf proposal depicts the pictogram of a vernacular ecology harmonized with the deeply rooted cultural texture of Hasankeyf in Southeastern Turkey. It presents an improved but closely paired to vernacular design that provides guidance for designers and builders who would partake in building dwellings for the soon-to-be-submerged city.

The proposed guidelines simply do not dwell upon a novel design; they instead focus on the 'recreation of the vernacular' with an enhanced environmental performance. It is nonetheless, acknowledged that the vernacular model faces constraints as passive design approaches are enforced. Considering this, design alterations to the vernacular model such as providing a glazed enclosure at terrace level to pre-heat the air to be supplied indoors and/or active systems would additionally need to be integrated to achieve full comfort.

All the unifying elements of the proposal are created to respond to the current family needs and environmental conditions for a building scale enhanced performance as discussed by (Yannas, 1994) along with finding a balance within the traditional composition of the area. It is through these considerations that the guidelines highlighted within this paper can be followed for a sustainable modern era adaptation of the new and soon-to-be emerging Hasankeyf dwellings.

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Session PC : Passive Design

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Grace - Knowledge Consortium of Gujarat

Office in the Tropics

Rastogi, Manit
[Morphogenesis, New Delhi, India]

Bansal, Nitin
[Morphogenesis, New Delhi, India]

ABSTRACT

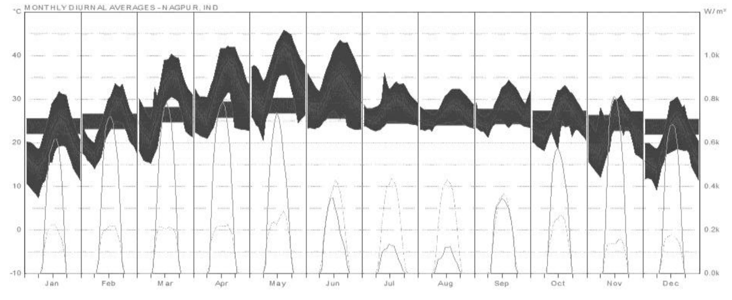
While designing a high-spec office complex for a multi-national organisation, the challenge lies in finding an integrated solution in terms of comfort and energy use while complying with the varying expectations due to the flexible nature of the users. The project was approached with the intention of creating an exemplar in environmental design with respect to naturally available resources, while minimizing site-disturbance. This would be achieved through an overall Net-Zero cycle of water, energy as well as an effort towards carbon neutrality. Façade efficiency encompasses both daylight and energy-use. The additional but vital criteria put forward by the client, for a 100% glare-free working space added to the challenge of optimizing fenestration design. The design process for the built-envelope therefore involved solar control, daylight distribution, glare control, and finally controlling heat loads from the built envelope by employing simple manual calculations based on principles of heat transfer.

1. INTRODUCTION

As a fast developing nation, India has seen rapid globalization in the recent past, and that is set to continue well into the near future. Consequently, the demand for smart office spaces with high specifications and all the latest modern construction techniques is booming. In a mainly warm-tropical climate such as India's, it implies an unnecessarily high dependence on external resources to operate optimally. The optimization of daylight and energy consumption is fundamental in building design and thus, pivotal in addressing the comfort aspirations of the users, where an equilibrium between visual and thermal comfort needs to be maintained. The contradictory objectives of maximizing daylight penetration and reducing glare are further compounded by the thermal implications of strong solar ingress. Drawing on lessons from the vernacular, solar protection strategies like façade shading and mutual shading prove to be an effective solution for warmer periods of the year. The opportunity of utilizing this solar ingress for thermal comfort is often encouraged during the cold season. However, the relatively low altitude of the sun during this period further complicates the task of achieving glare-free conditions. Being part of the global milieu whilst responding to the local context, is what this paper aims to highlight; a climate-responsive approach towards achieving thermally comfortable office design with primarily glare-free working conditions throughout the year in the challenging climate of Nagpur, India. The objective for the project was, *"to facilitate integration of solar-passive design principles with modern building design, and create an exemplar of an energy-efficient building."* The design process was simplified by reducing the time spent and dependency on analysis software at the concept stage, and instead relying on basic principles, using software to confirm the results (effect of) from the said calculations.

2. ANALYSING THE CLIMATE

The composite climate of Nagpur sees 18 weeks of hot-dry conditions with daytime temperatures often exceeding 30°C and reaching up to 45°C (Fig.1). During the next 14 weeks of the monsoon period (June-September), the city receives 1.07m of rainfall (annual average). The city experiences high humidity (60%-90%) and frequent precipitation together with daytime temperatures dropping below 35°C and remaining close to comfortable values (below 30°C) on an average. Climatic conditions, therefore, remain on the warmer side for most part of the year with a short period (6-8 weeks) of mild winters, with warm days and cool nights. The high intensity of incident solar radiation adds to the challenge of meeting the requirement for **100% glare free, 100% day-lit working conditions** with a maximum solar heat gain from the built-envelope being ≤ 1.0 W/ft^2 (of built-up area).



Typology	*: Corporate Office Complex*
Location	*: Nagpur,India (21.1°N,79.1°E)*
Status	*: In progress*
Site area	*: 142.18 acres*
Gross floor area	*: 73,327m^2/block (1,52,100m^2 total)*
Permissible FAR	*: 1.5 + 1*
Building height	*: 45m (12 floors)*
Building occupancy	*: 20,000 people*
Occupancy period	*: 9am-6pm*

***Figure 1**. Climate graph for Nagpur, India.*
(Source: Ecotect Weather Tool)

3. MASTER-PLAN

The master-planning process began with a basic assessment of the carrying capacity for the site on a net-zero cycle of water. This was followed by addressing the energy demands for the targeted occupancy further leading to the planning and allocation of services/resources on site (Figure-2).

3.1 Carrying Capacity for Water Demand

The 142 acre site gradually slopes down towards an adjoining artificial water tank (Dahegaon tank) ending in a 32 acre low-lying zone at the junction (Fig.2b). Considering the conventional annual water consumption of 45.0lpcd (domestic, flushing, HVAC and irrigation) the site was found to be sufficient for supporting 20,000 persons. Additionally, a water reservoir of approximately 20 acres (at a depth of 3m) was calculated for the said rainfall collection (Table-1). This reservoir was placed in the low-lying section of the site - as a visual extension to the existing water-tank- to effectively collect the surface run-offs from the natural topography.

3.2. Carrying Capacity for Energy Demand:

Once the carrying capacity was established, the gross built-up area for the project was defined with a targeted density of 130sq.ft per person. Targeting an 80% improvement over the baseline energy consumption of 140kWh/m2/yr. as per GRIHA recommendations, the primary energy consumption was estimated at 25kWh/m2/yr. with 35kWh/m2/yr. being load from equipment. The reduction in primary energy load (lighting and HVAC loads) as governed by robust building design has been discussed in sections-4 and 5 while the corresponding equipment loads were reduced by employing efficient systems (Table-3). The annual energy consumption for the project was thus, targeted/calculated at 60kWh/m2/yr. Integrating renewable resources to offset the energy demand presented a requirement of a 36 acre solar farm (Table-2).

Table-1. Carrying Capacity on Water Demand Cycle

Rainwater Harvesting potential		
Site Area	5,75,361	sq.m.
Annual rainfall	1.07	m/yr.
Run off factor	0.5	
Total rainwater collected	3,07,250	cu.m. /yr
Rainwater Harvesting potential *@20% evaporative losses*	2,45,800	cu.m. /yr
Water Consumption per person *@45.0L/person /day*	11.7	cu.m./yr
Carrying Capacity	**21,009**	**~ 20,000**

Table-2. Carrying Capacity on Energy Demand

Renewable Energy Resources		
Carrying Capacity for people	20,000	ppl
Built-up area @ 130ft^2 per person	2,41,548	sq.m.
Target EPI (Building Loads)	25	kWh/m2/yr.
Occupancy Loads	35	kWh/m2/yr.
Estimated Annual Energy Consumption	60	kWh/m2/yr.
Total Annual energy consumption	1,44,92,888	kWh/yr.
Required installed capacity of solar PVs*	9,662	kWp
Area required for installing solar PVs**	1,44,929	sq.m.
Area required for installing solar PVs	**36**	**Acres**

Table-3. Energy Consumption Parameters

Parameters	**Conventional Load Density (W/sq.ft.)**	**Improved Case (W/sq.ft.)**
Lighting Load	1.5	0.3
HVAC Load	4.5	1.0
UPS & Server Load	2.5	0.7
Raw Power Load	0.5	0.2
Utility Load	0.5	0.2
PHE Load	0.5	0.1
Total	**10**	**2.5**

*Estimated average of 1500kWh energy is generated annually per 1kWp of installed capacity in the case of Nagpur, India.

**Installing 1kWp of solar plant requires 15 sq.m.of land area.

3.3. Carbon emissions:

Creating a natural renewal cycle of the estimated resource consumption by the project was an imperative for achieving the minimum possible site-disturbance. This included attention to carbon sequestration as a step towards attaining carbon neutrality. The average annual greenhouse gas (GHG) emission for the project was calculated as shown in Table-4. Sequestration of these emissions was planned through afforestation given the site area available for the project. ***It was concluded that 71acre tree cover was sufficient to offset the annual per capita carbon emissions for the occupants of the office.***

Table-4. Carbon/ Greenhouse Gas Sequestration

Average per capita emission in India	1.2	tCO_2/yr
Avg. CO2 emissions per year for 20,000 persons	**24,000**	**tCO_2/yr**
Avg. carbon absorption per tree	0.012	tCO_2/yr.
Total no. of trees required for complete sequestration *(as per United Nations Environment Programme,2008).*	96,000	(@ 4 trees/tCO2[1])
Required area under tree-cover	**2,88,000**	**(71acre)**
Annual sequestration	100%	

[1] *Plant For The Plane : The Billion Tree Campaign*. An Album. ISBN : 978-92-807-2896-5, United Nations Environment Programme,2008

3.4. Site-Planning

Preliminary planning based on principles of environmental design helped define zoning and resource allocation as illustrated in Figure-2. The water reservoir was designed as a lake, adjoining the existing water-tank in the low-lying area of the site. This facilitated effective rainwater collection from the surface run-offs mainly due to the sloping terrain. Moreover, the location of the lake was an opportunity for utilizing the South-South-West summer winds, enhancing the microclimate on site by evaporative cooling. Water canyons were designed along radial roads in the South-South-West direction to further enhance the cooling effect along pedestrian walkways. The 36-acre solar farm was placed towards the Southern part of the site for maximizing the available solar energy. The building-zone (26 acres) was seated overlooking the 'lake' to maximize on the benefits of evaporative cooling. The strategic location of the proposed building was further enhanced by views of the lake on one side while 60 acres of the 71 acre green cover was proposed for the remaining site area on the opposite side. The balance 11 acre green cover was planned to be integrated within the building zone. The building zone was further divided into 4 parts (5.5 acres each) based on the carrying capacity (5000 persons each), for optimally phasing the master-plan.

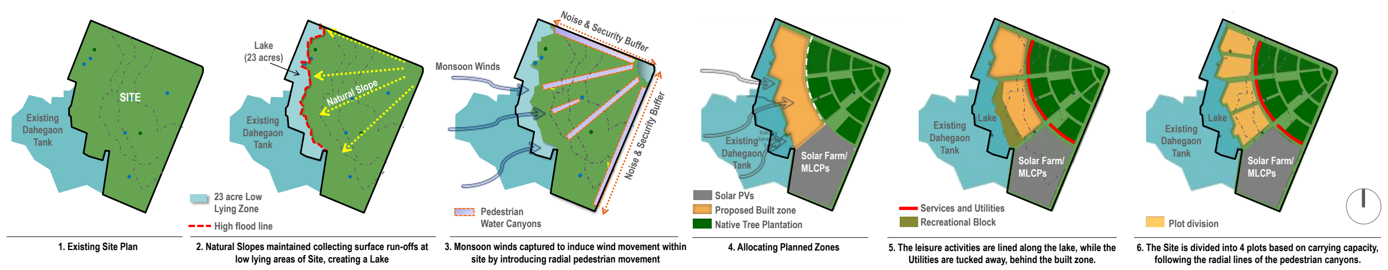


Figure 2. ***Site plan showing master-plan development for the project***

4. BUILT FORM

4.1 Floor-Plate Design

The design methodology for the built-form was formulated with visual comfort in the work-space as the priority. The basic environmental criteria of providing 100% day-lit working spaces governed the design for the typical floor-plate. Based on the principle that the extent of daylight penetration in a building floor plate is 2 times the height from the floor to top of the window, the ideal depth of the floor plate with a 4m height was limited to 16m. The programme brief specified a requirement for 90 workstations and corresponding facilities for a single module. This module was optimised around a core shared by 2 modules, such that common facilities are accessible by all 180 employees. Moreover, building regulations for accessible fire-escapes limited the maximum length of the floor plate to 100m (max. distance between 2 staircases must not exceed 90m).

In order to accommodate the required 180 workstations with peripheral circulation, the width of the floor-plate needed to be increased from 16m to 18m (Fig.3a). This decision gave rise to the challenge of increasing the daylight penetration inside the space. The consequent steps undertaken to achieve 100% day lit work-spaces have been discussed in the following section. The final design for the typical floor-plate was developed with an efficiency of < 100 ft^2/ person (Fig.4b).

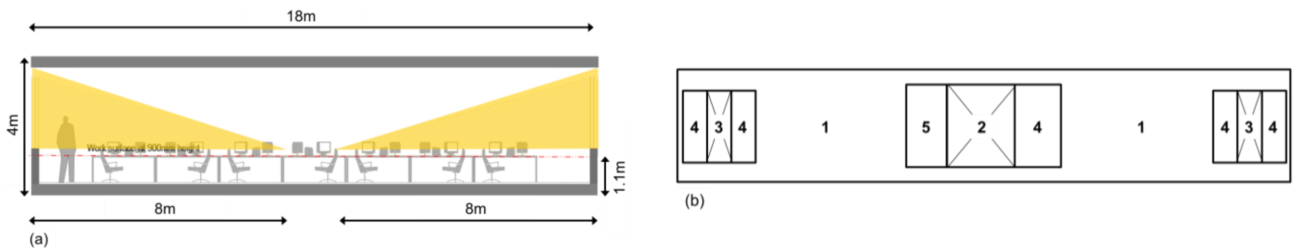


Figure 3*(a) Daylight penetration in the typical module (b) Typical Floor-plate resulting from design brief and preliminary daylight thumb-rules: 1. Workstations (90x2), 2. Main service core, 3.Fire-escape, 4.Meeting Rooms, 5.Facilities*

4.2 Morphology

The orientation of the building was determined based on the sun-path diagram as explained in Fig. 4. Due to the location of the site at 21.15ºN 79.09ºE, a pure N-S orientation is vulnerable to both the morning as well as evening sun of an azimuth angle of up to 21.15°. However, rotating the building by a similar angle (on either side) naturally results in obstructing the solar azimuth for at least half the day. This meant that the solar control devices could now be designed for single sided protection, also simplifying the architectural implications. Finally, it was concluded that ***for the given location orienting the plan at 22.5° reduced the shading requirement on either façades.***

The founding stratum of soil on-site was primarily a Basalt Stone and would not permit high structural settlements and the allowable bearing pressures were expected to be high. A maximum of 10 to 12 storey structures were possible in accordance with the maximum permissible height, which was also restricted by laws regarding aviation caps in the area. Furthermore, the architectural intention was to break the tower down to a more *human-scale*, bringing the users closer to the level of the landscape and creating a relationship with the outdoor environment. The building was thus, divided into 3 blocks of 4 floors each. Here, the 4 floors were stacked on each other forming a tube with a capacity of 720 employees. These modules were then staggered at 22.5° either ways and at 45° overall, mutually shading each other, and as a result, creating 'new-ground' or break-out spaces as shown in (Fig.5). The stacked tubes were further multiplied (total 8 blocks) to accommodate a total of 5000 persons. Various cases for interlocking these modules were explored in order to determine the most robust morphology for the complex (Fig.6). The objective was to design for flexibility in the configurations in terms of future expansion of the complex while maintaining the self-sufficient character of the blocks. The resulting morphology was a network of shaded courtyards and open terraces. (Fig.7)

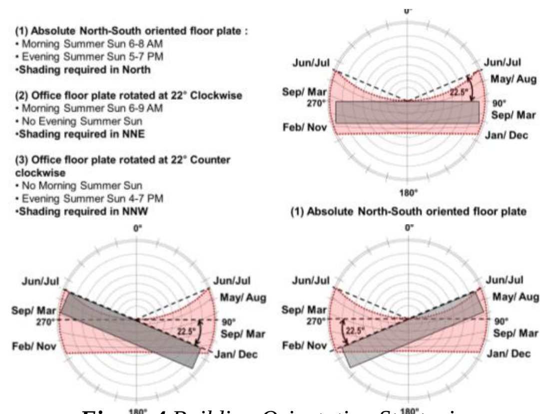


Figure 4 *Building Orientation Strategies*

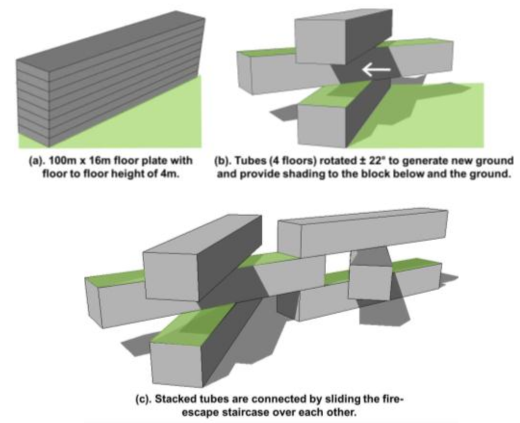


Figure 5 *Developing the building morphology*

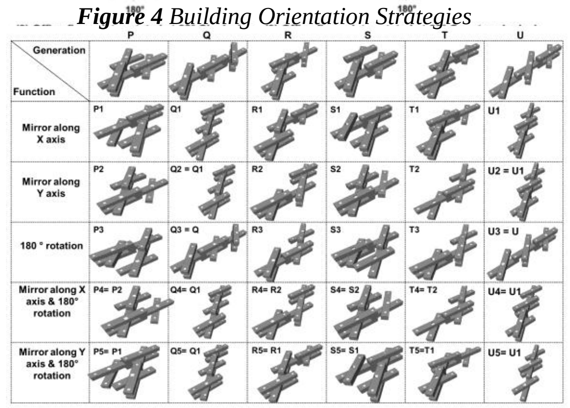


Figure 6 *Exploring potential configurations for the 8 blocks*

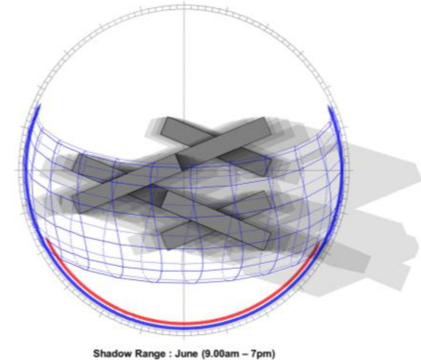


Figure 7 *Overall massing*

5. PERFORMANCE INDICATORS

The process of integrated daylight and thermal performance evaluation also addresses glare as an integral parameter for visual comfort. The design of the built envelope was, therefore, governed by the following parameters:

- ***Solar Control:*** Manual calculations, Ecotect analysis
- ***Glare***: Ecotect analysis
- ***Distribution of Daylight***: Ecotect, Radiance analysis
- ***Heat Loads***: Manual calculations

Devising a method of simple manual calculations (on a Microsoft Excel spreadsheet) allowed for simultaneous cross-checking of the thermal implications of each step taken while designing the fenestrations.

5.2. Solar Control

Solar shading design for a typical opening on each of the four orientations (NNW-SSE and NNE-SSW) was carried out. The basic window size was taken as 2.4m x 2.1m with sill level of 1.1m. The first step involved identifying the critical angles [2] to be shaded during the occupied period of the day i.e., 9am to 6pm. These angles helped define the optimum shading angle and therefore the depth of shade required. Designing for angled louvers was discouraged for this context, to avoid obstructing the pleasant views overlooking the landscaped surroundings. It is important to highlight that in north facing windows, the direct solar ingress is due to the summer sun i.e., when the altitude as well as the azimuth are relatively higher. Thus***, the shading for north-facing windows was designed for the Summer Solstice (21st June) where the azimuth angles were critical***. Figure 8(a) represents the shading design process for a typical window facing North, North-East. It was concluded that 422mm deep vertical fins spaced at 600mm c/c could be adopted for North, North-East orientation as this solution helped maintain views across the entire height of the window while effectively shading the morning sun.

Following the same methodology 600mm wide fins spaced at an overall 600mm c/c proved to be optimum for North, North-West facing windows. For reasons of architectural economy, it was decided that the depth of the vertical fins should be uniform for both northern orientations (NNE, NNW) i.e., 600mm deep fins with 600mm c/c spacing.

Solar controls for south facades were designed considering 21st December (winter solstice) for peak design parameters because the sun drops down to the lowest altitude levels (0.6° at 5.30pm). Here, the solar altitude was identified as the critical angle. It is important to highlight that Nagpur tends to see mostly clear sunny skies and so the tendency of experiencing glare is quite high. The need for shading the low winter sun in addition to the summer sun was a challenge arising due to the target set for the project to achieve 100% glare-free working conditions. ***Direct visibility of the sky from a user's level (1.25m) and glare-causing sun patches from the upper part of the window were therefore a key concern.*** A solution for this was to obstruct the bright sky view from the upper end of the window.

Consequently, the window was divided in 2 equal parts-

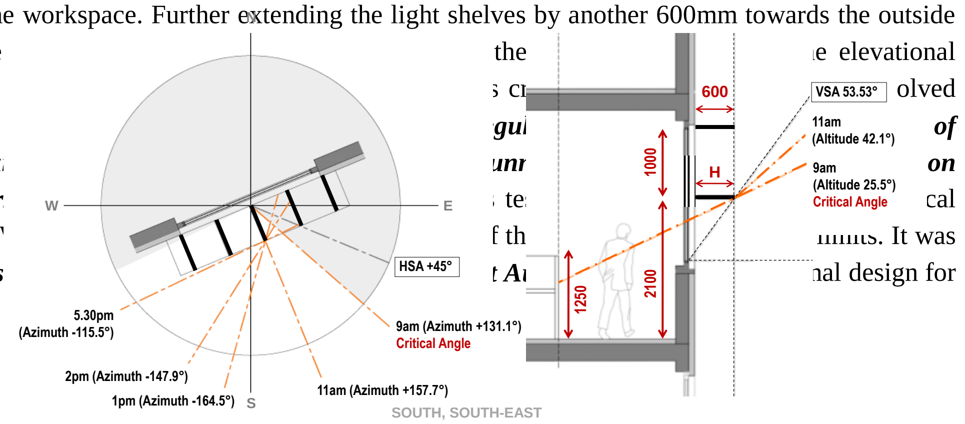
- **Daylight Window at 2.1m**: Frosted in order to diffuse possible glare patches
- **Vision Window at sill level of 1.1m**: 50% visible light transmission (clear)

In the case of south facing windows, (Fig.8c,d), both the SSW, SSE windows tend to get direct solar radiation the entire day from 9am to 5.30 pm (sunset). Also, the altitude drops significantly after 4pm and goes as low as 0.6° at 5.30pm on the 21st of December (extreme case) making shading at this angle highly impractical.

While designing for the South, South-East windows (fig.8c), it was observed that vertical fins of depth and spacing of 600mm were effective for obstructing the sun after 11am till 5.30pm. Horizontal overhangs were explored for providing shade for the remaining morning period. A combination of both horizontal and vertical projections was therefore, required to shade the opening up till 11 am. Furthermore, distancing the workstation at 1.5m from the glazing and the partition facing this corridor was designed as an effective obstruction for the 9am sun as a strategy to provide shade without making the shading projections too deep. The role of the shading devices was reversed for the south, south-west window where the vertical fins were now effective from 9am to 11am and overhang helped distance the direct sun from the workstation (Fig.8d). The workstation design comes into play up till 4pm. This protected the worktop without compromising on the visual comfort of the user. However, it was observed that beyond 4:15pm the intensity of solar radiation is not high enough to cause glare and may be acceptable in the current scenario. ***The resultant shading device is a system of fixed horizontal and vertical shading fins varying with the solar exposure of the windows.*** Figure-9 represents the shading effect of the solar control devices.

4.3. Daylight Distribution and Glare Control

Due to high frequency of bright skies, the average illuminance was expected to be above acceptable limits. However, optimizing the distribution of this daylight within the floor-plate (18m depth) needed to be investigated. Also, dividing the window in 2 parts, with half the total opening being frosted, was bound to further affect the daylight penetration inside the building. Internal light shelves were therefore explored as an effective strategy for this condition and were integrated with a 600mm depth at 2500mm height. South facing windows suffer from direct solar radiation for most part of the day. Despite frosting the daylight panel, the high levels of external illuminance could lead to the panel itself becoming extremely bright. This aspect was countered through light shelves at 2500mm which obstructed the direct view of the daylight panel from the occupant's seated level. Additionally, a comparison of the insolation on the various orientations influenced the decision to reduce the overall window area on the southern facades. This was done by introducing a solid band (insulated) of 400mm below the light shelf, reducing the area of the daylight panel. The resultant was a z-section with the light shelves at 2500mm, external overhang at 2100mm and a 400mm wide solid band in between (Fig.10a). For northern orientations, the daylight available is diffused and therefore, glare-free. This fact was exploited by the addition of internal light shelves on the northern facades which were expected to increase daylight distribution inside the workspace. Further extending the light shelves by another 600mm towards the outside led to a significant improvement in the ... the ... e elevational elements (as the south windows) and at ... olved compliance with LEED 2011NC criteria ... ***of 10 foot candles (fc) (110lux) to a max*** ... ***on September 21st at 0900 and 1500 hour*** ... cal unobstructed floorplate oriented NNE|SS ... It was observed that ***overall 100% of the spaces*** ... nal design for windows has been illustrated in Fig.-1



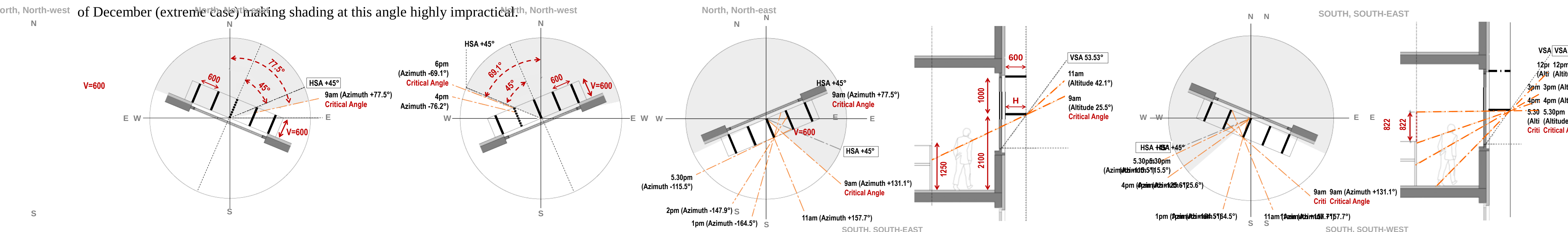
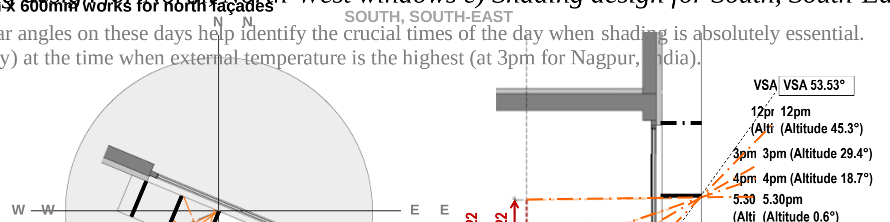


Figure 8. (a) Shading design for North, North-East windows (b) Shading design for North, North-West windows c) Shading design for South, South-East windows. (d) Shading design for South, South-West windows

[2] Peak design conditions for shading design are Summer Solstice (21st June) and Winter Solstice (21st December). The solar angles on these days help identify the crucial times of the day when shading is absolutely essential.

[3] Peak design conditions for heat load calculations in warm climates are considered for the hottest day of the year (23rd May) at the time when external temperature is the highest (at 3pm for Nagpur, India).



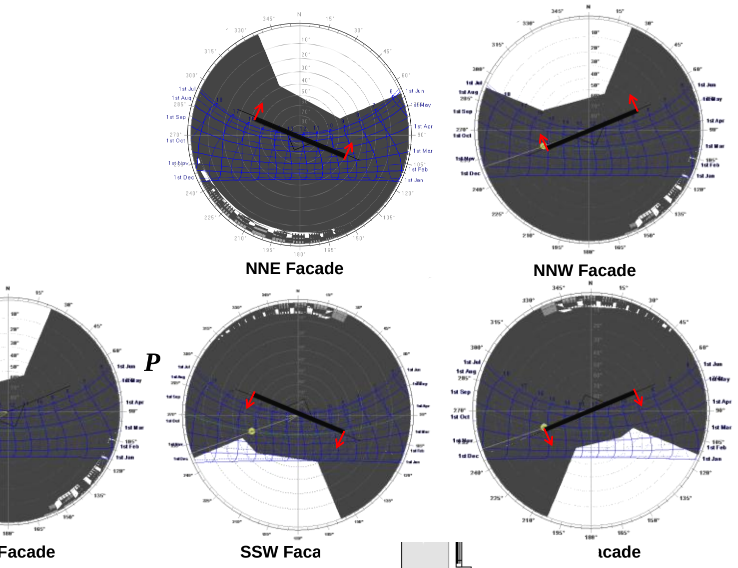


Figure *hading design* ***Figure 10****.Daylight analy* *(NNE/SSW)*

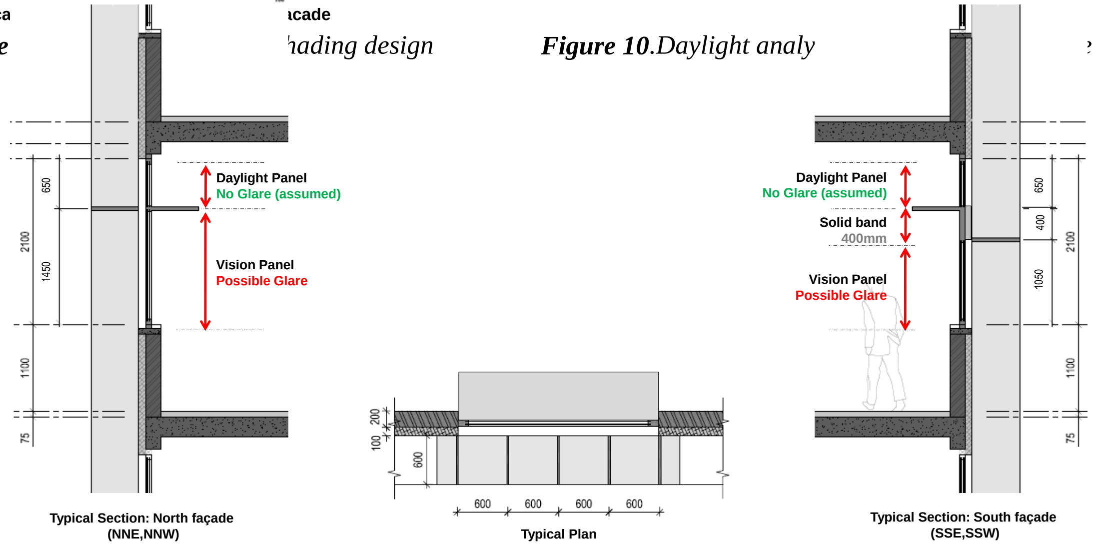


Figure 11*. Designing solar control for fenestrations*

5.4. Thermal Efficiency

The cumulative solar heat gains (W/m^2) of the designed façades, resulting typical module and complete building were calculated to assess the overall thermal efficiency of the envelope**. *The maximum solar load from the building envelope was targeted at ≤1.0W/ft^2 with an intention to achieve the lowest possible value without compromising on the design principles for the project.*** The formulae and methodology adopted were based on heat transfer principles for opaque and transparent building elements (Table-5) as advised by the Energy Conservation Building Code-2007. Figure-12 illustrates the methodology followed to calculate the thermal efficiency of the building. The key parameters were identified as:

- Window: Wall Ratio (designed at 22.5%)
- U-values of fabric (Walls, Slabs, Glazing)
- Effective Solar Heat Gain Coefficient of Glazed Elements

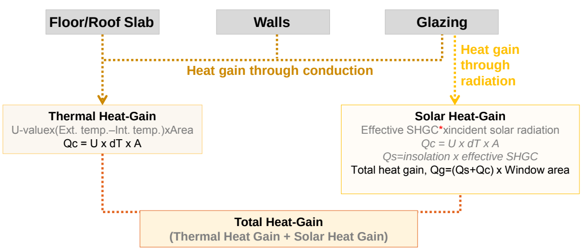


Figure 12. *Methodology to calculate cumulative heat gains*

Table-5 Thermal Properties of Building Elements

Orientation	U-value (W/m^{2}k)	Effective SHGC
Roof Slab	0.317	-
Walls	0.345	-
Daylight Panel-SSW	1.040	0.15
Vision Panel-SSW	1.040	0.03
Daylight Panel-NNE	1.040	0.14
Vision Panel-NNE	1.040	0.13

The heat gain process through opaque elements like walls and slabs of a building mainly comprises heat gain through conduction. Transparent building elements, on the other hand, have higher vulnerability to heat gain through solar radiation in addition to conductive heat gain. Heat gain from solar radiation is based on the solar heat gain factor (SHGC) of the glass which, in turn, depends on the specifications of the glass and on the angle of incidence. Owing to the solar shading design, the effective SHGC in this case was much lower than the maximum SHGC which played a significant role in reducing the overall heat gain from incident solar radiation. ***Finally, the solar heat gain for the entire building was calculated and resulted in an overall thermal efficiency of 0.79W/sq.ft.***

Figure 13. *Resulting Design of the Office Complex (Nagpur, India)*

5. CONCLUSION

This paper presents the process followed to achieve a holistic solution for efficient climate sensitive design of an office complex for composite climatic conditions. Sound integration and planning of the renewable resources available on site helped achieve a Net-Zero cycle of energy and water consumption. The conscious decision to restrict the buildable zone allowed for ample tree cover for natural sequestration of carbon emissions during the life cycle of the building. Orienting the building along the North-South axis at 22.5° either ways significantly reduced solar exposure. Efficient solar control design helped achieve a 100% glare-free and fully day-lit working environment with a minimal WWR of 22.5%. A robust building envelope was created by further pushing the thermal performance of the fabric to achieve thermal efficiency well below the 1.0W/ft^2 mark. The success of the entire process is clearly demonstrated by the fact that all the pre-requisites for the project were met within respectable limits, coming together in an architecturally relevant design.

6. ACKNOWLEDGEMENTS

We would like to thank the members of our project design team Sonali Rastogi (Founding Partner, Morphogenesis), Apul Tandon (Associate, Morphogenesis), Piya Gupta (Architect, Morphogenesis) for their hard-work and dedication.

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Morphological Variation Impact on Heating and Cooling Energy Consumption in Buildings

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ABSTR ACT HEADING

This study quantified the impact of morphological variation on the heating and cooling energy consumption in buildings. Using the eQuest simulation program, a series of parametric simulations was conducted to derive the amount of heating and cooling energy consumptions for the numbers of floors, floor areas, and space volumes. Numerical tests were performed in a typical two-story single-family residential building located in the two different climate zones in the USA – the hot/humid and cold regions. Analysis revealed that the amount of heating energy in the cold climate was the most significant component in buildings: thus, an energy-efficient heating system and energy-conscious operation needs to be considered for saving energy. In addition, the amounts of heating and cooling energy were all proportional to the building's number of floors, floor area, and volume of space. Therefore, the building is required to be planned based on the morphological impact on the building energy efficiency.

INTRODUCTION

The survey results conducted by the Ministry of Knowledge Economy of South Korea in 2009 indicated that almost quarter of the annually consumed energy in Korea was used in buildings (22.3%). Among this amount, 51.0% was used by residential buildings. In addition, 63% of the energy in residential buildings was consumed by single-family houses and 37.0% was used by multi-unit dwellings. Thus, single-family houses and multi-unit dwellings respectively accounted for 7.2% (=0.223*0.51*0.63*100) and 4.2% (=0.223*0.51*0.37*100) of the total national annual energy consumption. The heating and cooling systems consumed 58.1% of the total energy used in residential buildings. Therefore, it can be inferred that 6.6% (=(7.2+4.2)*0.581) of the total national energy was consumed for heating and cooling in residential buildings (Moon, 2011a; Ministry of Knowledge Economy, 2009; Lee, 2006).

Numerous researches have been conducted regarding energy-efficient building thermal-control theories, systems and control technologies. The reinforced insulation level of building envelope was proved to be one of the most significant determinants for increasing building energy efficiency (Kim & Moon, 2009; Moon, Han, & Oh, 2011; Moon, 2011a), and the optimal controlled ventilation and infiltration was able to improve heating and cooling efficiency as well as to comfortably condition the indoor air quality (Moon, 2011b). In addition, the optimal control strategies for operating thermal-control systems have been widely investigated using state of the art control theories such as artificial intelligence (Moon & et al. 2014; Moon & Han, 2012; Moon, 2012; Moon & Kim, 2010). In particular, Kim has conducted a research on the relationship between the width-to-depth ratio (W/D), the surface-

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to-volume ratio (S/V) and on the heating and cooling loads, in which heating and cooling loads were proportional to the W/D and S/V (Kim, 2013).

Energy savings and CO2 productions by the building is expected to be remarkably impacted by the building configuration. This study, thus, aimed to investigate the quantitative impact of morphological building variation on the amount of energy consumption for thermal conditioning. In order to accomplish the research objectives, the energy consumption pattern according to the changes in the number of floors, floor area, and space volume was analyzed for a single family house located in two different climate regions (cold climate: Detroit, Michigan, USA; hot and humid climate: Miami, Florida, USA). The numerical simulation method was applied for the tests and the findings of this study will be used as sound fundamentals for planning the energy-efficient and environment-friendly residential buildings.

RESEARCH METHODS

For calculating energy consumption by the morphological changes of building, a test building was modeled **as shown in Figure 1**, which has the typical features of a U.S. single-family house (U.S. Census Bureau, 2005). It is a two-story, south-facing, flat-roof building installed windows without shading devices and doors. An identical building was employed for the tests in two different climatic regions: hot/humid climate (Miami, Florida, USA) and cold climate (Detroit, Michigan, USA). The climatic conditions of Seoul, South Korea and of the two U.S. cities are **summarized in Table 1**. As Seoul, South Korea shows similar climatic conditions with Detroit, Michigan, USA, the outcomes for the cold climate will be more applicable to understand the Korean conditions.

The heat transfer coefficients of walls, roof, floor, windows and doors were 0.31, 0.16, 0.24, 1.64, and 2.00 W/m^2K, respectively, which were lower value than standards for both Miami, Florida and Detroit, Michigan. Window-wall-ratio of envelopes was 0.15 in average with 0.20 for south, 0.10 for north, 0.15 for east and west. In addition, 0.30 ACH (air change per hour) was applied for ventilation and infiltration rate (Haysom & Reardon, 1998). As internal heat gains, four people and their hourly weighted heat and moisture gains (ASHRAE, 2004a; McArthur 2004), lighting fixtures with 5.38 W/m^2 for living area, 12.8 W/m^2 for storage, 13.8 W/m^2 for laundry, and miscellaneous with 3.2 W/m^2 for living area and 1.6 W/m^2 for laundry were applied.

For space heating and cooling, a furnace (26.70 KW for Miami, Florida; 31.67 KW for Detroit, Michigan) and DX colis (16.55 KW for Miami, Florida; 14.06 KW for Detroit, Michigan) were installed considering the normal and setback periods for energy saving based on the occupancy schedule. The set point temperatures in the normal and setback periods were 22.22°C (72.0°F) and 15.56°C (60°F), respectively, for the heating system, and 25.56°C (78°F) and 27.78°C (82°F) for the cooling system. The normal and setback periods were different among weekdays, Saturdays, and Sundays and holidays **as shown in Table 2**.

The eQuest3.63 numerical simulation tool, which is an acronym of the quick energy simulation tool and was based on the DOE-2.2 of by the U.S. Department of Energy (DOE) and Lawrence Berkeley National Laboratory, was applied for calculating the annual heating and cooling load and the energy consumptions according to the morphological building changes (eQuest, 2009). The validity of this program for further simulation has been confirmed in the previous studies (Kim & Moon, 2009; Moon & Han, 2011; Moon, Han, & Oh, 2011; Moon, 2011a; Moon, 2011b). The test period was the year 2012, and the TMY2 weather data were employed for the hot/humid and cold climates.

The test variable for analysing the energy consumption patterns were number of floors, the floor area, and the volume of space as **summarized in Table 3-5**. The basecase of the first variable was a two-story building **as given in Table 3**. Based on the base case, one- and three-story buildings were comparatively simulated. The total floor areas of three cases were identical while the areas of the walls, floor, and roof were changed. For example, compared to the basecse, the three-story building had a larger wall area but significantly smaller floor and roof areas while the one-story building had a reduced wall area but increased floor and roof areas.

The basecase of the second variable was a building with 224.5 m^2 (2,400 ft^2) floor area **as given in Table 4**. With the basecase, five variations for the building area by the changes in width and depth were tested. No changes in the number of floors and in the building height were considered.

The basecase of the third variable was a building with a volume of space 303.0 m^3 (21,600.0 ft^3) and five variable cases based on the change in building height were tested **as given in Table5**. The other components such as buiding width, depth, and number of floors were not changed from the basecase.

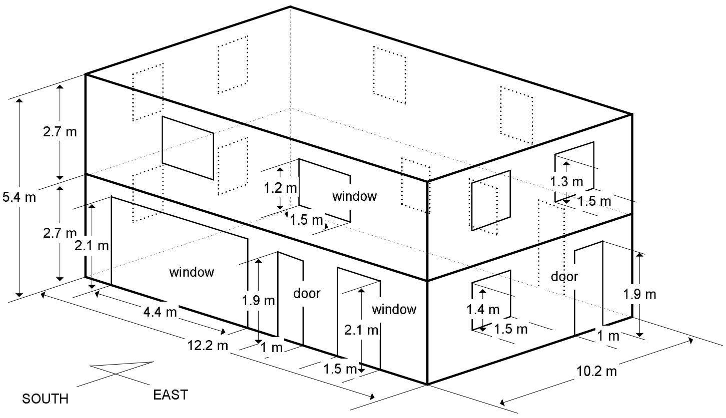


Figure 1 The test building.

Table 1. Comparison of Climate Conditions of Cities

Regional Factors	Seoul, Korea	Miami, Florida, USA	Detroit, Michigan, USA
Latitude (°)	37.55N	25.82N	42.23N
Longitude (°)	126.8E	80.28W	83.3W
Annual average temperature (°C)	12.2	24.4	9.2
Annual precipitation (mm)	1,344.3	1,419.9	828.0
Design temperature for heating-99% (°C)	-12.1	9.8	-15.1
Design temperature for cooling-1% (°C)	30.1	32.0	31.0
Heating degree day (°C*Day)	2,500~2,700	200	3,649
Cooling degree day (°C*Day)	600~800	4,198	626

Table 2. Schedules for the heating and cooling System Operation

Days		Hours	Set-point temperatures (°C)	
			Heating system	Cooling system
Weekdays	Normal	0:00~8:00, 18:00~24:00	22.22°C	25.56°C
	Setback	8:00~18:00	15.56°C	27.78°C
Saturday	Normal	0:00~8:00, 14:00~24:00	22.22°C	25.56°C
	Setback	8:00~14:00	15.56°C	27.78°C
Sunday & holiday	Normal	0:00~24:00	22.22°C	25.56°C
	Setback	-	-	-

Table 3. Change of the Number of Floor

Number of Floor	Width (m)	Depth (m)	Walls (m^2)	Floor (m^2)	Roof (m^2)	Total Envelope (m^2)	Note
1	17.3	12.9	163.1	223.2	223.2	609.5	
2	12.2	9.2	231.1	112.2	112.2	455.5	Basecase
3	10.0	7.5	283.5	75	75	433.5	

Table 4. Change of the Building Area

Floor Area (m^2)	Width (m)	Depth (m)	Height (m)	Number of Floors	Note
93.2	7.9	5.9	2.7	2	
138.2	9.6	7.2	2.7	2	
186.5	11.1	8.4	2.7	2	
224.5	12.2	9.2	2.7	2	Basecase
277.4	13.6	10.2	2.7	2	
370.5	15.7	11.8	2.7	2	

Table 5. Change of the Volume

Volume (m^3)	Width (m)	Depth (m)	Height (m)	Number of Floors	Note
269.4	12.2	9.2	2.4	2	
303.0	12.2	9.2	2.7	2	Basecase
336.7	12.2	9.2	3.0	2	
381.6	12.2	9.2	3.4	2	
415.3	12.2	9.2	3.7	2	

RESULT & ANALYSIS

Annual Heating and Coolin g Loads

The annual heating and cooling loads were presented **in Figure 2**. In the hot/humid climate region, the cooling load (43,284 KWh) has taken most of the load (43,447 KWh). The heating load was just 164 KWh. On the other hand, the heating load (10,041 KWh) was significantly larger than the cooling load (1,910 KWh) in the cold climate region.

The total amount of heating and cooling loads was 4.3 times larger in the hot/humid climate compared to that in the cold climate. This is mainly due to the significantly larger cooling load in the hot/humid region. However, the total amount of annual heating and cooling energy will not differ as was the loads since the efficiency of the cooling system is normally higher than that of the heating system. That is, the increased heating load is directly proportional to the increased heating energy in the cold-climate region while the increased cooling load is relatively less effective for the increased cooling energy in the hot/humid-climate region.

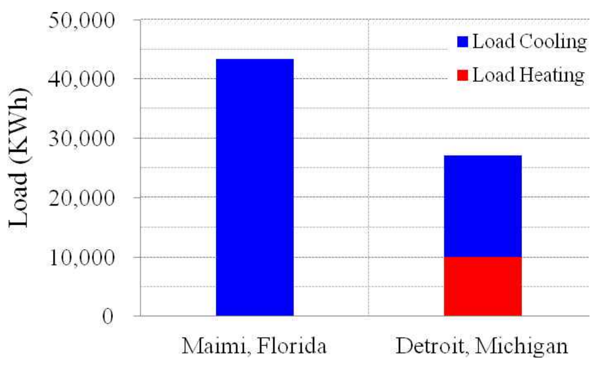


Figure 2 Annual heating and cooling loads for two climate regions.

Amount of Heating and Cooling Energy Consumption According to the Morphological Variations

Number of Floors. The energy consumption pattern for different number of floors is compared **in Figure 3**. The amount of heating and cooling energy increased as the number of floors increased. This is due to the fact that as the number of floors increased, the roof and floor surface area, which had relatively smaller heat transfer coefficients, decreased while the wall area, which had a larger heat transfer coefficient, increased. The increasing ratio was 92.26 KWh/floor for heating and 1,010

KWh/floor for cooling in the hot/humid climate region. Compared to the basecase, which is two-story building, the one-story building saved 7.8% and 9.5% of heating and heating energy, respectively. On the other hand, the three-story building comsumed 8.3% and 18.0% more energy for heating and cooling.

Identical to the hot/humid climate region, the amount of heating and cooling energy increase when the number of floors increased in cold climate region. Their amounts reached as much as 1,364.8 KWh/floor and 340.0 KWh/floor for heating and cooling energy, respectively. Compared to the base case, the one-story building saved 20.4% and 1.37% energy for heating and cooling while the three-story building used 15.2% and 5.8% more energy for heating and cooling. This analysis indicates that the low-rise building can be more energy efficient for a buiding with same area.

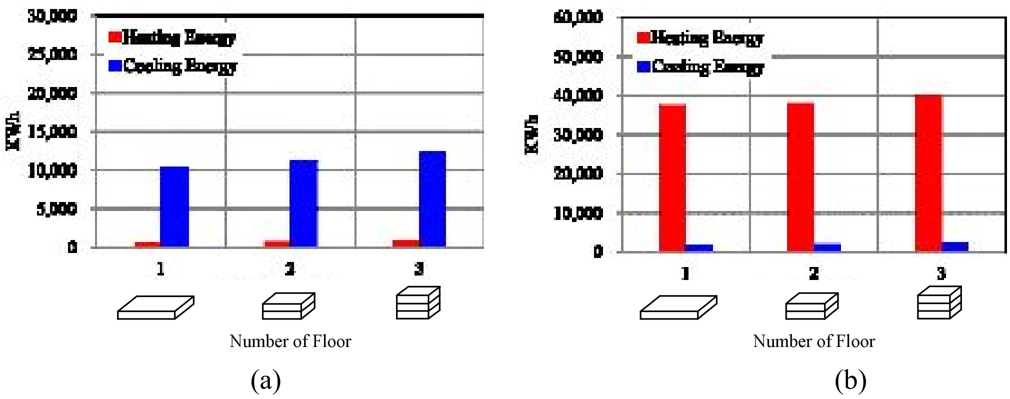


Figure 3 Amount of heating and cooling energy by different building floor: (a) Miami, Florida, USA, (b) Detroit, Michigan, USA.

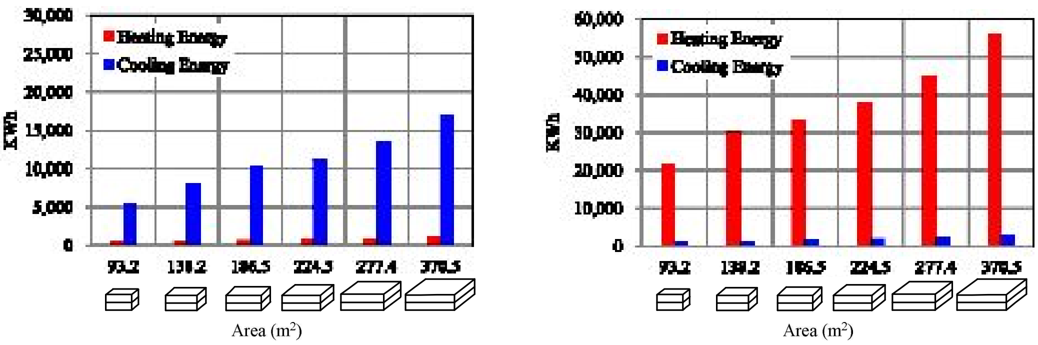
Floor Area. The energy consumption for the change of floor area is shown **in Figure 4**. The cooling energy significantly increased in the hot/humid-climate region as much as 41.83 KWh/m^2 while that of heating energy was 1.73 KWh/m^2. The case of the smallest building area saved 27.0% heating energy and 52.1% cooling energy. On the other hand, the case of the largest building area has comsumed more energy by 40.2% for heating and by 50.5% for cooling. However, the amount of energy consumption per floor area was reduced as the floor area was increased. For example, the heating and cooling energy consumption was respectively 5.6 KWh/m^2 and 58.2 KWh/m^2 for the smallest building while those of the largest building were 2.7 KWh/m^2 and 45.94 KWh/m^2.

Similarly in the cold climate region, more heating and cooling consumed as the floor area increased. The increase ratio was 124.71 KWh/m^2 for heating and 6.61 KWh/m^2 for cooling. Compared to the base case, the smallest building saved 50.4% and 43.5% of heating and cooling energy, respectively while the largest building consumed 45.5% and 47.6% more energy for heating and cooling. However, similar to the hot/humid region, the amount of heating and cooling energy per floor area was decreased for the larger building. 230.21 KWh/m^2 and 10.17 KWh/m^2 were used in the smallest building while 151.25 KWh/m^2 and 7.50 KWh/m^2 were consumed in the largest building. Based on the analysis for the change of floor area, it can be concluded that the properly planned building area can be beneficial to improve building energy performance.

Volume of Space. Figure 5 compares the amount of heating and cooling energy for the change of space volume. Voluminal change was more related to the cooling energy increase in the hot/humid climate region as much as 14.6 KWh/m^3. The amount of heating energy increase was 0.94 KWh/m^3. Compared to the base case, the least-volume buiding saved 4.9% of heating energy and 4.5% of cooling energy while the largest-volume building used more energy as much as 14.0% for heating and 14.8% for cooling.

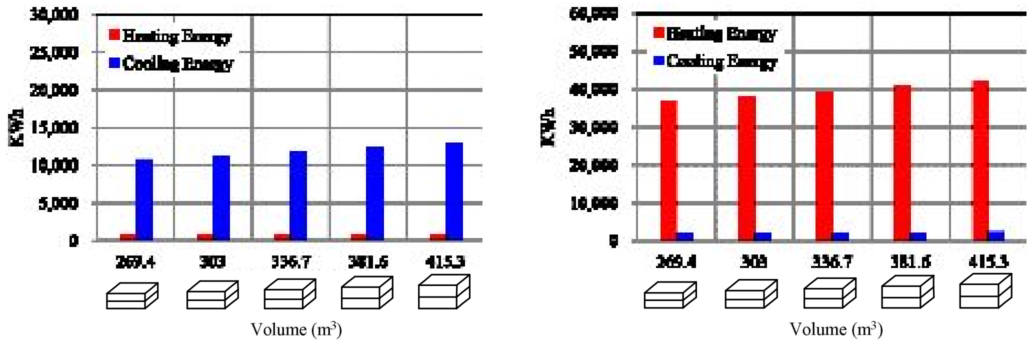
In the cold-climate region, the heating energy increase ratio was far more significant (37.7 KWh/m^3) than that of the cooling energy (3.77 KWh/m^3). In addition, the increase ratios were more significant than that in the hot/humid climate region. Compared to the basecase, changes in the heating and cooling energy for the least- and largest-volume buildings were 7.3% and 3.6% reductions and 21.5% and 10.9% increases, respectively.

However, similar to the analysis result for the floor area, the amount of heating and cooling energy consumption per space volume was reduced as the largest-volume building was applied. The amount of heating and cooling energy per spaced volume for the least-volume building was 2.53 KWh/m^3 and 39.94 KWh/m^3 for the hot/humid region and 135.91 KWh/m^3 and 6.57 KWh/m^3 for the cold region. Those of largest-volume building were reduced to 1.97 KWh/m^3 and 31.04 KWh/m^3 for the hot/humid region and 101.40 KWh/m^3 and 5.59 KWh/m^3 for the cold region.



(a) (b)

Figure 4 Amount of heating and cooling energy by different building area: (a) Miami, Florida, USA, (b) Detroit, Michigan, USA.



(a) (b)

Figure 5 Amount of heating and cooling energy by different building volume: (a) Miami, Florida, USA, (b) Detroit, Michigan, USA.

IMPLICATIONS & CONCLUSIONS

The objective of this study was to investigate the energy consumption pattern by the morphological variation of buildings. For this, typical U.S. single-family houses with different number of floors, floor area, and volume of space were numerically modeled and comparatively tested for two climatic regions; hot/humid climate and cold climate. Below is a summary of the study findings.

(1) The cooling load was larger than the heating load in the hot/humid climate region while the heating load was larger than the cooling load in the cold climate region. The total amount of heating and cooling loads was 4.3 times larger in the hot/humid climate compared to that in the cold climate.

(2) The amount of energy used for heating and cooling increased along with the number of floors since as the number of floors increased, the roof and floor surfaces having lower heat transfer coefficients became smaller while the wall area having a higher heat transfer coefficient became larger.

(3) The heating and cooling energy increased as the floor area became larger. In particular, the cooling energy used in the hot/humid climate region and the heating energy used in the cold climate region predominantly increased.

(4) The amount of energy used for thermal conditioning was found to be proportional to the volume of a building. Identical to the change in the floor area, the cooling energy used in the hot/humid climate region and the heating energy used in the cold climate region remarkably increased. The increase ratio was larger in the cold climate region.

(5) The amount of energy per area or volume was reduced as the larger buiding was applied in both climate regions.

From the analysis, it can be concluded that the morphological variation in residential buildings has a direct impact on the amount of energy consumption for building thermal conditioning, and based on the findings, proper planning of floor numbers, size and volume need to be considered to advance the building energy efficiency. This study was conducted in only two cities in the U.S.; thus, performance tests for cities with other diverse climatic conditions and for Korean cities are warranted in the futher studies. In addition, data analysis is required for the actual results from existing buildings.

ACKNOWLEDGEMENTS

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Digital Process: environment analysis of intermediary spaces in the context of Brazilian modern dwelling.

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ABSTRACT HEADING

Europe of the beginning of the 20th Century: the desire to break away from the past and transform domestic spaces following the modern movement was clear. But there was a part of this production which sought to project the dwelling space based on traditional ideas. There are attributes of vernacular architecture, will be considered in the production of this time.

In this context we gave the focus of the study, looking at the veranda within the domestic environment of modern architecture in Brazil.

The veranda, as an intermediary space, was present in distinct eras of Brazilian housing, and together with this transformed itself of form, use and meaning.

The proposal of this investigation is to study the veranda as an architectural element, intermediary space and domestic living area, with the intention of identifying the distinct interpretations, from the formal and the principal elements from an environmental point of view. The analyses also look in which the domestic environment was incorporated into modern architectural production.

The second part of this investigation deals with the object of the study: the veranda as an intermediary space. This is undertaken by the presentation and analysis of case studies selected to represent the distinct compositional resolutions of the intermediary space in the modernism period (1930-1965).This study cases were also redraw, using digital tools which simulate incident solar radiation, thermal and lighting analysis. This helped to identify the solutions related to the comfort thermal and luminous of internal areas and observe the veranda as a step between interior and exterior, always considering different environments in this context.

INTRODUCTION

The Europe of the early twentieth century presented a panorama of major changes in different areas of life and knowledge, especially when it came to scientific and technological advances that eventually influenced, by new theories and concepts, the artistic production.

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Among other issues, modernity sought to change the way of think and project dwelling space, which in this research will be discussed from the point of view of the intermediary space of the veranda. At the same time, Brazil was looking to find their own ways in the artistic and architectural production.

Although it was clear the desire to break with the past and transform the domestic space guided by the ideals of the modern movement, there was a part of this production that wanted to design and build the living space based in tradition. There are a number of attributes of vernacular architecture, which will be taken into account in the architecture of this time.

BASIC TYPES AND VARIATIONS

Separate by typologies the intermediary space conformed by the veranda was appropriate from the beginning, when reduce to one type the complexities of an arquitectonic object it is not perceived yet.

That is why the expression compositional resolution appears as a synonym for explaining these works, considering not only the intermediary space but other transition spaces from the home environment.

For this research, it was necessary to establish a selection criterion that could better represent each study case. Examples are sought in the major mass media of the time, looking at the theoretical and practical production of architects considering its importance for Brazilian architecture in this context. With this, it was proposed to look at these selected houses, from the point of view of the intermediary spaces.

Nine modern houses made between 1930-1965 are chosen to represent each compositional resolution

After an initial reading and considering the before mentioned methodology, five basic formal design structures for the veranda in the contexto are established:

1- Veranda by Horizontal Plane extension

2 Veranda by Horizontal / Vertical Plane extension

3 Veranda by Subtraction

4 Veranda by Addition

5- Veranda by Pilotis

Identify and synthesize into five basic types allow us to separate case studies by groups of similar formal structures (with its variations).

With this, an understanding of the works is done, not only analyzing its formal qualities, but also the relations between the interior and the exterior, the permeability between these two environments and consequently the privacy levels.

Classify the works by typologies also help to identify when the veranda is designed with reference to tradition and (or) when is innovation.

At first, a look at the vast repertoire of modernity is done to find examples that accurately approach to the compositional resolution in its most essential form (or that could be "conceptually reduce" to one type). From this idea, the Mendes House by architect Oscar Niemeyer and Spartacus Vial by David Libeskind were selected to represent the way to design the veranda in their respective type.

On this same reflection, Osmar Gonçalves House by Oswaldo C. Gonçalves is chosen because of its formal simplicity and clarity to identify separately the volume of the main house ant the intermediary space.

Guilherme Brandi House was a little different, because there were other houses that might better represent the idea of typology by extension of the horizontal and vertical plane. But although the house has a simple volume, some items such as the facade composition, awaked some curiosity to study. Another reason for study this Sergio Bernardes house would be the variety of how this architect works the intermediary space in the domestic architecture.

It was slightly different the decision to choose Beira Mar residence. Being the typology that is closer to the traditional architecture (and this has never ceased to be part of the modern repertoire), traces of modernity in both function and formal composition were sought to find in the examples. This work of Oswaldo Bratke was the most appropiate to represent the compositional resolution of the veranda, from a floping extension of the roof.

Trying to approximate (reduce) to one type, I realized that there were other reasons that led us to study these spaces, and is fot that, that other reasons were considered appropriate for the selection.

To represent the compositional resolution identified as horizontal plane extension, an easy reading was pretended. But looking at some Oscar Niemeyer works (both Canoas house and Dalva Simão house and another house build much later in France following the same concept), a different way to conform the intermediary space from the prolongation of the curved roof is perceived: the curve that characterizes the Brazilian architecture should be contempled here.

Other reasons that led me to define the election were the different purposes of the veranda in the same house, like in Saavedra House, besides being clearly appropriate to represent the space generated through the inverted roof.

Magalhães Gouveia House would be the example more difficult to fit in a typology, but because of being a unusual roof design for the time (and that it is a proper addition) was choosed to do the analysis under this point of view.

Finally, we have the well known Carmen Portinho house by Reidy, for the way the architect incorpores (later) the veranda in the space liberated by the pilotis (without having the original function of pilotis).

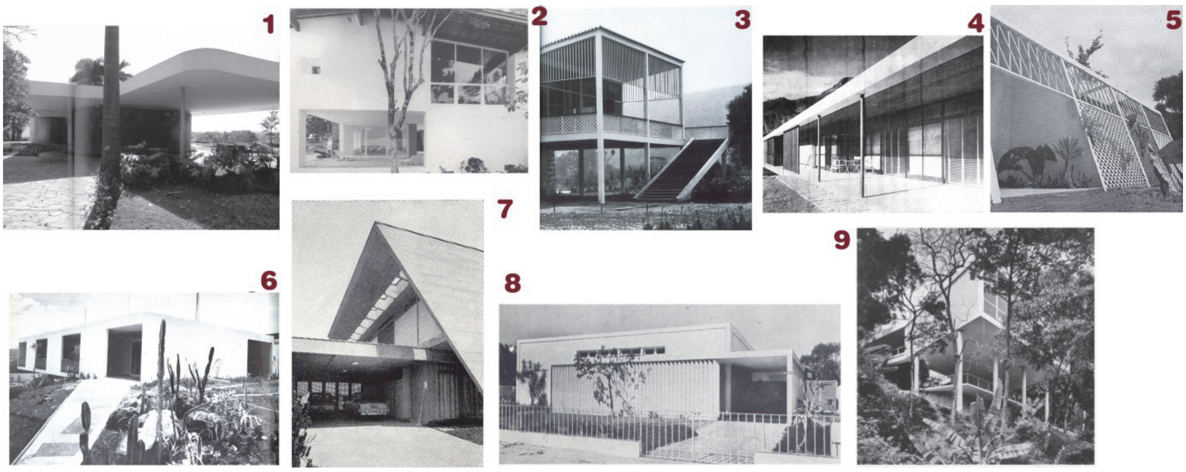


Imagem 1-Casa Dalva Simão (Oscar Niemeyer), Fuente: MACEDO,2008. 2-Casa Beira Mar (arq.Oswaldo Bratke), fonte: SEGAWA;DOURADO,1997.3-Casa Saavedra (arq. Lucio Costa), Fuente: MINDLIN, 1956.. 4- Casa G. Brandi (arq. Sergio Bernardes), Fuente: revista Acrópole, Nº 301, 1963.. 5- Casa Mendes (arq. O.Niemeyer), Fuente: PAPADAKI, S., 1950. 6- Casa S.Vial (arq.D.Libeskind), Fuente: TROMBI, 2007. 7-Casa M.Gouveia (arq. C.Lemos e E.Corona), Fuente: Revista Acrópole, Nº 313, 1965.. 8- Casa O.Gonçalves (arq. O.Gonçalves), Fuente: Mindlin, 1956. 9- Casa C.Portinho (arq.A.Reidy), Fuente:Bonduki, Nabil (org),

STUDY CASES

In recent years, we have witnessed a technological revolution. The architecture is also a reflection of this situation, since there are new tools that have changed the way we work. Creation possibilities have increased, as well as accuracy. These new tools give new possibilities that allow more experimentation through simulation.

Using Ecotect software, we intend to analyze the works considered as representative of the different typologies for the varanda, pretending to find some answers related to both thermal and lighting, from the viewpoint of the presence of the intermediary space.

The analysis will be divided into five main points:

a) Shadow analysis

In this analysis we will proceed to simulate the cast shadow by the intermediary space in itself and the adjacent room. With this analysis, it is intended to reach some conclusions as to verify if the situation of the veranda is determined by the solar orientation or because of terrain conditions.

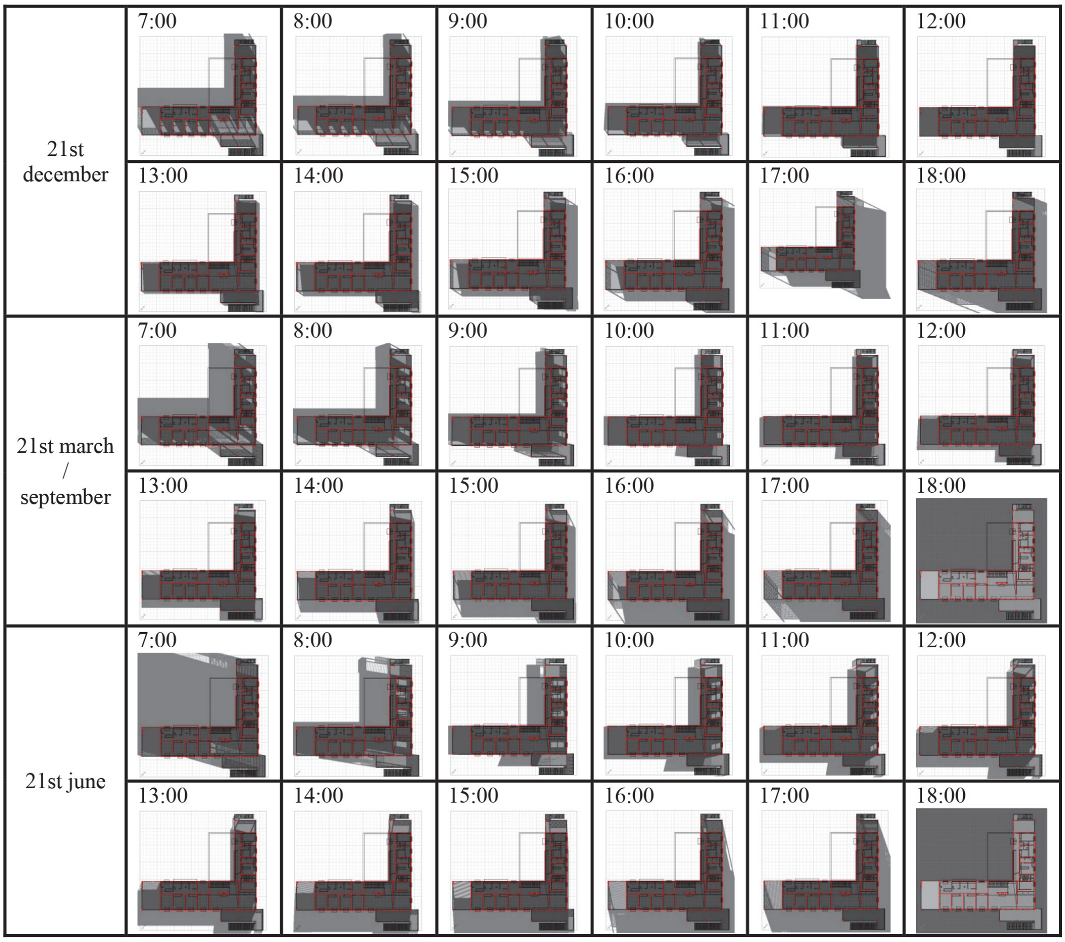


Figure 1. Saavedra house veranda shadow analysis

This house has 3 verandas (1-SO 2-SE, 3-NO). Each receives direct sunlight at different horaries due to its orientation, so each one can be enjoyed at its moment.

Dalva Simão house – The north facade is the only one that is connected to the exterior through big openings and it only recieves direct sunlight during the winter, while in summer the roof extensión that conform the veranda protects the interior from the direct sun.

Guilherme Brandi house - Receive the solar incidence relatively constant throughout the whole year, during the afternoon.

Mendes house - Receive morning sun, and is during the summer the highest exposure.

Osmar Gonçalves house – Incidence druing the afternoon but the presence of the protection makes the veranda suitable to use.

Carmen Portinho House- The internal veranda recieves the sun in the afternoon, and is in winter when the exposure is lower, while the external veranda (pilotis), that has the same orientation, receives direct sunlight in the early hours of the day too.

b) Solar radiaton analysis

It will proceed to calculate the solar radiation in the intermediary space and the contiguous room, in the four year seasons between 7:00 and 18:00, expressed as average daily values. With these results we try to see the influence of the varanda on the adjacent rooms and its solar radiation.

SOLAR RADIATION ANALYSIS					
House		Spring	Summer	Autumn	Winter
Dalva Simão		1134,23	1208,46	1233,63	1284,64
Casa Saavedra	1	1203,65	1286,4	828,5	841,99
	2	1044,13	1107,22	768,36	771,28
	3	1305,15	1429,07	1382,26	1382,49
Guilherme Brandi		691,9	734,07	395,96	415,64
Casa Mendes		1193,78	1270,92	775,97	812,73
Osmar Gonçalves		626,9	984,36	573,29	564,17
Carmen Portinho	Interior	908,97	952,67	561,18	527,12
	Pilotis	1134,23	1208,46	1233,63	1284,64

Figure 2. Solar radiation table results

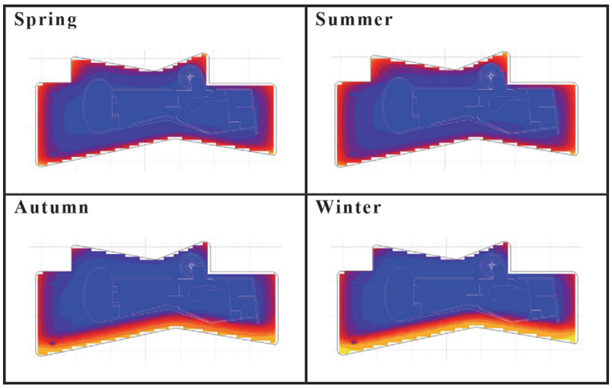


Figure 3. Dalva Simão solar radiation

We can observe that all of the houses receive more solar radiation during the spring and summer, except Dalva Simão house, that is because its orientation and roof design that makes autumn and winter when the higher levels of solar radiation (as we can see in the figure above).

c) Daylighting analysis

For the calculation of daylighting factors the Ecotect uses a geometric version of the Split Flux Method (BRE) and Design Sky values that are derived from a statistical analysis of outdoor illuminance levels. They offer a worst-case scenario that you can design to and be sure your building will meet the desired light levels at least 85% of the time.

This simulation will be made at 0,75m from the ground level, to see if the adjacent room to the veranda achieves the lighting levels established by the brasilian standard NB-57.

DAYLIGHT ANALYSIS		
House		Lux
Dalva Simão		363,45
Casa Saavedra	1	369,33
	2	377,82
	3	298,59
Guilherme Brandi		338,57
Casa Mendes		215,89
Osmar Gonçalves		190,76
Carmen Portinho	Interior	362,26

Figure 4. Daylight levels table results

All of the residences achieve good levels of daylighting, making them suitable even for reading, except Osmar Gonçalves house, and Mendes house, because of the protection.

d) Sun incidence on facade analysis

With this analysis we try to see when the façade under the veranda receive the direct sun.

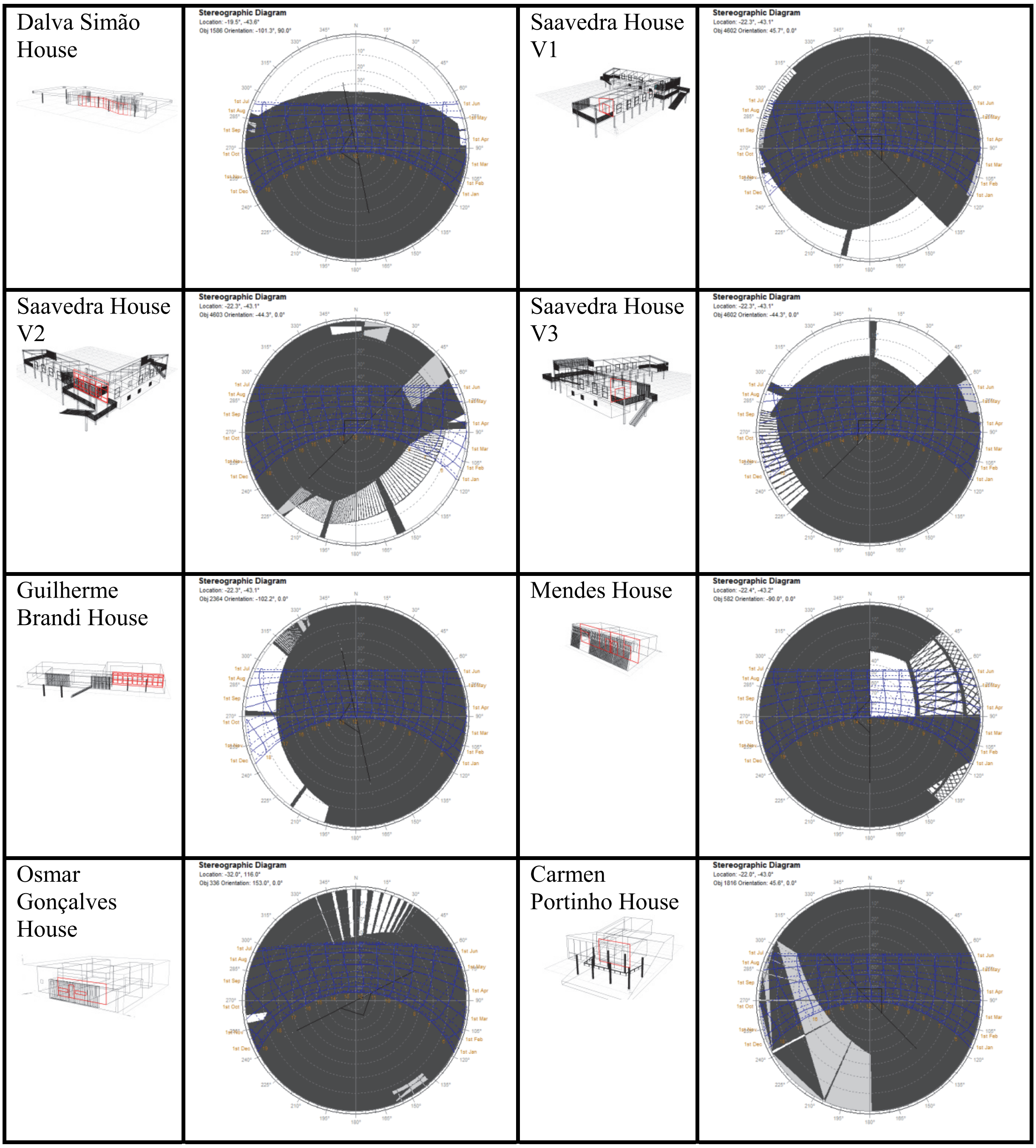


Figure 5. Stereographic diagrams on facade

e) Sun protection on facades analysis

For this analysis, we propose to analyze the residences that have some kind of enclosure in the veranda to protect from the solar incidence. The simulation is done with the enclosure and without, so to compare the two situations, and verify the most efficient for each context.

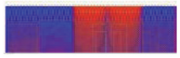
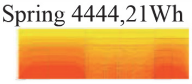
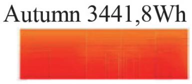
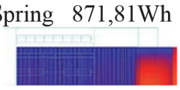
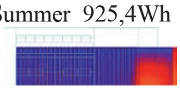
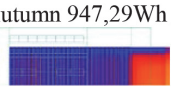
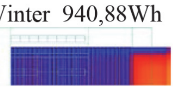
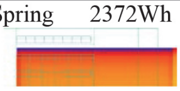
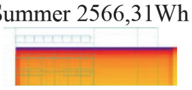
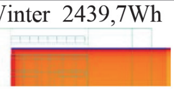
Mendes House	With	Spring 1932,32Wh 	Summer 1523,79Wh 	Autumn 906,76Wh 	Winter 900,21Wh 
	Without	Spring 4444,21Wh 	Summer 4762,48Wh 	Autumn 3441,8Wh 	Winter 3327,63Wh 
Osmar Gonçalves House	With	Spring 871,81Wh 	Summer 925,4Wh 	Autumn 947,29Wh 	Winter 940,88Wh 
	Without	Spring 2372Wh 	Summer 2566,31Wh 	Autumn 2446,45Wh 	Winter 2439,7Wh 

Figure 6. Solar radiations on facade

Considering the Brazilian weather and the orientation of these spaces, we can see that the election of the architects about putting a protection is a good solution, achieving a solar radiation reduction between 60%-70%.

CONCLUSIONS

Being a quite extense study, we can confirm that in the architectonic production of the modern Brasil there was a search for a design diversity of the intermediary space, as so the variety in functions. The design of this space was also to work with a second skin for the building, and in this way adapt the international language to the climatic context.

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Municipalities Leading the Way to a Low-Energy Building Future

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ABSTRACT

What happens when a municipality becomes the owner and builder for an innovative low-energy project? Marken Projects joined forces with a small group of motivated individuals from the City of Fort St. John's in northern British Columbia to build a passivhaus that would serve as a demonstration project for future developments in the city. This project is not only one of the first completed passivhaus projects in British Columbia, but at 56 degrees north latitude, it is the most northern in Canada, matched only by one in Finland. It serves as an example of the important role that municipalities can play in introducing new ways of building and new technologies. It has been used as a demonstration to teach builders and homeowners about passivhaus and low-energy building design. The City will be able to communicate lessons learned and best practices observed through constructing and monitoring the project themselves, and by validating technologies not typically used in Fort St. John. They have already succeeded in breaking down local pre-conceptions about energy efficient homes during the construction process. By taking on the role of General Contractors, they faced challenges that lead to increased costs and longer construction timelines but the practical knowledge they gained from building the project themselves outweighed these challenges. Upon completion of the home in the autumn of 2014, it will eventually be sold at market value making this a break-even project for the City. They will retain ownership for three years following completion in order to complete the building commissioning, monitor its energy performance and hold open houses for the community to experience this house and learn more about it. This type of leadership role by a municipality can go a long way towards changing the way building happens.

INTRODUCTION

Marken Projects Design Studio joined forces with a small group of motivated individuals from the City of Fort St. John in northern British Columbia in 2011 to build a passivhaus that would serve as a demonstration project for future developments in the city. This project is not only among the first completed passivhaus projects in British Columbia, but at 56 degrees north latitude, it is the most northern in Canada, matched only by one in Finland. There were many reasons that the City of Fort St. John's took on the challenge of becoming owner/builder of their own passivhaus project. Many municipalities in British Columbia are reluctant to consider such an endeavour. Three long years since its inception, the house is finally near completion. But whether after all of our efforts, The City can declare the project a success, is still undecided. They have set extremely high expectations for themselves before they are ready to do so. In this paper we discuss the motivation and challenges in making this project happen; we describe the project and the future plans for leveraging it to change local building practices. This project serves as an example of the important role that municipalities can play in introducing new ways of building and new technologies.

Ayme Sharma is a building designer and Managing Director for Marken Projects Design Studio, Vancouver, BC.
Dianne Hunter is the City Manager of Fort St. John, BC. Marty Paradine is the former Energy Manager, Fort St. John, BC

PROJECT INCEPTION

Fort St. John is a city of about 18,000 residents in northeastern British Columbia. It is a unique community that is experiencing tremendous growth driven by development in the energy sector, particularly in the unconventional natural gas sector. The City's slogan is *The Energetic City*, referring to energy derived from the region's natural resource exploration and to a tangible mantra for the attitude of the residents. Boasting one of the highest birth rates in the province and an average age of 31 years, many young families move to Fort St. John as they see within it great opportunities to build a solid financial future for their families while also enjoying a great quality of life.

Living in the heart of the province's energy sector (natural gas, hydroelectricity, wind farms, coal, geothermal) the environmental impacts of how energy is extracted from natural resources is a stark reality for Fort St. John. They are part of the region in the province that produces the greatest proportion of energy for export per capita thereby affording others a high quality lifestyle. From this "backyard" vantage point, they can clearly understand the importance of minimizing the environmental impacts of energy extraction by looking to better ways of generating energy. In British Columbia, there are many communities with resource extraction based economies. The residents of these communities are often perceived as having little interest in environmental issues. In fact, with an abundance of resources and the natural beauty surrounding these communities, it is not difficult to understand why environmental concerns such as energy conservation are not a priority for residents. Fort St. John stands out as a very progressive community that takes stewardship of the environment seriously. Over the past 7 years, they have aimed to become an environmental leader in the Peace River region through the use of pervasive sustainable and environmental best practices. Their approach is to prioritize conservation as one of the easiest and best sources of energy. If a rural, northern community with an extraction-based economy can show this type of environmental leadership, there is hardly an excuse for others not to follow in their footsteps. Their projects have been numerous:

- They partnered with BC Hydro to hire one of BC's first Energy Managers, making energy a strategic focus of the community.
- They developed a Community Energy and Emissions Plan (CEEP) to improve energy efficiency, reduce greenhouse gas emissions and foster green energy solutions in the community.
- They have developed a Carbon Neutral Plan for taking action on reducing emissions from municipal operations.
- They have significantly reduced water use in the community through metering and toilet change-out incentive programs.
- They have launched innovative projects such as the micro-hydro project that will use wastewater to generate power to sell back to the utility company – protecting the environment while using a liability as an asset.

The turning point that led to the inception of the passivhaus stemmed from a proposal from BC Hydro (a provincial electric utility) to build a third hydro dam on the Peace River. The dam, referred to as Site C, will be located 7 km from the downtown center. The City is working to protect their community from the negative impacts of this dam. The dam will flood thousands of acres of arable land that could be producing food for the community. Once flooded, this land will be lost forever. The dam would not be necessary if all homes in Fort St. John were constructed to the passivhaus standard. This harsh reality motivated the City to take action to demonstrate extreme energy conservation.

APPROACH

The passivhaus concept was promoted by the City's Energy Manager and supported by the entire organization including City Council and senior management. The passivhaus project was perceived as an opportunity to:

- Demonstrate that building a home that consumes approximately 80-90% less heating and cooling energy than a typical code-built house is possible in Fort St. John.
- Demonstrate to local builders that highly energy efficient homes can be built at comparable prices per finished square

foot as homes built to building code standards in Fort St. John.

- Demonstrate different building techniques and innovative products and technologies.
- Build a net-zero energy ready building in accordance with their Carbon Neutral Plan.

Budget Problems

Funding for the passivhaus was approved through the City's budget process in 2012. The passivhaus was part of the Capital budget and was funded through industrial taxation. The house will eventually be sold at market-value and this money will go back into the Capital budget reserve. In this way, the project was envisioned as a break-even project for Fort St. John. The initial construction budget was $300,000. It was naïve to assume that the project could be constructed for this amount, especially when new houses in Fort St. John cost around $500,000. Lack of experience in this type of project led to poor budgeting resulting in having to go back to Council on two occasions for additional funds; this created tension within the working group and some negative backlash from the community. A major unexpected factor that increased costs was that the City had to assume the role of general contractor.

Disinterest in the Building Community

The City did not begin the passivhaus project with the intention of becoming the builder. After the design and construction documents were completed, they issued a call for tenders, but received only one respondent. The construction market is so busy in Fort St. John that there were not many builders interested in taking on the challenge of building something new. Fort St. John is a rapidly growing community with limited development resources. Local developers are struggling to provide for a rapidly expanding market. They are conservative in their construction practices and choose to maintain the standard construction practices and building styles that have worked well for them in the past. There is no need for developers to take risks with new techniques and products in this market. This fueled the desire of the City to demonstrate to builders that passivhaus construction is feasible in northern B.C. and that offering this kind of construction could be a competitive advantage over time, as the province becomes even more proactive on climate change. This is what led the City to take on the role of general contractor, which has resulted in many challenges that have slowed down the construction of the house and increased costs. As the price of housing escalates, the push for change will likely come from the end consumer who is looking for affordability, not only in the initial price of the house but in the ongoing operating costs. It is the City's objective to educate the consumer who will then seek a change in construction style from the local builders.

OUTCOMES

The Fort St. John passivhaus is a 2000 sqft 2-1/2 storey home with 3 bedrooms, 2.5 bathrooms and 1 flex room. The house is designed to be universally accessible. Construction of the house broke ground in January 2013. The Prefabricated thermal envelope panels traveled 700km north from the factory in Williams Lake, BC to arrive onsite in March. The panels were erected in 10 days. Following this, the windows were installed and the thermal envelope was taped and sealed in the spring of 2013. The thermal envelope is described in **Table 1**.

Figure 1 (a) Prefabricated thermal panels arriving on site. (b) Erection of the panels was complete within 10 days.

After this, the construction progress suffered from long delays, first due to the need to procure more funds from City Council; then due to heavy workloads of staff. The project also suffered from staff turnover and attrition, which is very typical in a northern community. Once the construction momentum fell off track, it was very difficult to convince busy subtrades to complete the remaining work. The drywall was not completed until early spring of the following year.

Thermal Envelope	Thickness	Assembly	Effective R-Val
Walls	18.75 in.	11-7/8" TJI prefabricated wall system paired with a 2X4 Service Wall	56
Roof	21.25 in.	16" TJI prefabricated roof system 2X3 service ceiling	70
Floor	16 in.	ICF perimeter, backfilled, 12" XPS R52, 4" concrete top slab on grade	52
Windows	-	Optiwin Al2Wood Windows (aluminum exterior and wood interior)	8
Doors	-	Euroline triple paned entry doors with thermal inserts and exterior cladding	8

Table 1: Thermal envelope: wood construction with cellulose insulation and ROXUL batt insulation in the service walls; SIGA tapes and membranes were used to achieve airtightness

The mechanical system consists of a direct-ducted ventilation system with heat recovery (HRV) and a combination of electric resistance heating (baseboards) and point source air conditioning (air source heat pumps) for backup heating and cooling. Domestic hot water is provided by a hybrid electric heat pump. This system will consumes about 90% less energy than a typical code built house due to an extremely energy efficient building envelope. The heating/cooling cost for the year is estimated to be $200-$400, which amounts to annual savings of approximately $1000-$1800 when compared to a house built to provincial building code standards in this climate. The house is net-zero energy ready, meaning that it is an ultra-efficient building that can be adapted to net-zero energy at a later date through implementation of renewable energy technologies on site. A 2.82kWp solar photovoltaic (PV) system installed on the roof will produce about 3500 kWhr/year (~25-30% of the homes total energy requirements). The remaining southern portion of the roof is prewired with electrical junction boxes for future PV expansion. Energy monitoring equipment is installed with an on-line analytics subscription for monitoring.

Figure 2 (a) Heat recovery ventilator installed in upper level closet. (b) Outdoor installation of air source heat pumps.

This home is 100% electric, utilizing provincial hydro-electric power. Using air-source heat pumps in the house with backup electric baseboards installed throughout, the house will emit 0.05 tonnes of GHGs per year — over a 99% reduction in tonnes of GHGs relative to a typical single-family detached dwelling. A single-family detached dwelling emits around 10 tonnes of CO_2 per year, on average. An airtightness level of 0.6 Air Changes per Hour @ 50pa or below is anticipated (pending blower door test). By comparison, an average home built in the 2000s in Canada would be at 3-4 ACH@50pa.

The final construction cost has not been tabulated, as the project is not yet completed. The City has approved a total of $580,000 for construction. Thus far, the cost of the house remains on par with the cost to build a new home in Fort St. John. With the value of the land included, the cost is $350 per square foot, similar to newly constructed homes in Fort St. John. Typical new build prices in Fort St. Johns range from $330-$380 per finished square foot.

Performance Ratings. Pre-certification as a passivhaus was achieved through PHIUS. The house also achieves a preliminary Energuide Rating of 90, is certifiable as LEED Platinum (should dual certification be sought) and is Net-zero Energy Ready.

Figure 3 (a) Exterior view from the northeast. (b) Exterior view from the southeast.

INFERENCES AND CONCLUSION

In spite of the delays due to budget issues and lack of experience as general contractors, the execution of the passivhaus has been excellent. It has been constructed exactly as designed. Upon completion of the home in the autumn of 2014, the City will retain ownership for 3 years in order to complete the building commissioning, monitor its energy performance and hold open houses for the community to experience this house and learn more about it. During this time the home will be rented as temporary housing for staff recruited to work for the City. Having an employee live in the home will allow flexibility in arranging for tours, demonstrations, etc. The house will be rented to a family to ensure the City is gathering real-time data that reflects the intent of the demonstration: a single-family residence. It will eventually be sold at market-value making this a break-even project for the City. But even though the City may be able to recover all of their costs, the money is not an indicator of the success of this project. The knowledge gained by the City cannot simply remain with them. A rigorous education and marketing plan is currently in development to ensure that the passivhaus does not become a stand-alone project. The City needs to ensure that they are not simply describing and demonstrating *what* a passivhaus is to the community of Fort St. John, but that they are able to sell the community on their vision for *why* they did it. If they are successful, then this small single-family residence can mark the beginning of a new building movement in Fort St. John. The education and marketing plan includes:

- Utilizing the house as a laboratory whereby builders and the public can see how the house actually performs.
- Providing tours, workshops and training opportunities for the public to understand the simple construction concepts around the passivhaus and how they can be replicated in the community.
- A Construction Manual and that can be provided to other builders.
- Web updates of energy consumption on the City's website.
- A Home Owner's manual

For the City, the markers of success include (1) verification that the final cost of construction is the same or similar as a typical single-family home in Fort St. John, (2) confirming that the performance of the house meets the anticipated energy conservation levels, (3) the uptake by private developers that initiate new projects to the passivhaus standard and finally (4) motivating community members to prioritize energy conservation in the design and construction of their homes. Success for the City of Fort St. John may ultimately mean that energy expansion projects such as the proposed Site C hydroelectric dam will not be necessary.

During construction, the project has been used as a demonstration to teach the local building community about passivhaus construction and low-energy building design. There have already been small signs of success in breaking down local pre-conceptions about energy efficient homes. The subtrades on-site expressed that they saw the value in ideas such as a service wall and prefabrication. One contractor has even decided to build his own passivhaus for his family. Smaller builders preferred the prefabricated building techniques since they could be erected quickly and were more manageable for smaller crews. This removes some of the construction risk associated with the high cost of labour in the region and the extremely short construction season, making it possible for them to compete with bigger construction companies. A City Building Inspector that took the lead as the General Contractor saw the benefit of becoming a Certified Energy Advisor (CEA) to help facilitate future lower energy building projects in the region. When he completes his training, he will be the first CEA in Fort St. John. As 1 of only 3 city building inspectors, this type of training will offer him great insight into evaluating and influencing the energy performance of construction in Fort St. John.

The City employees that are involved in completing the house since the thermal envelope was sealed have reported exceptional indoor comfort and consistent indoor temperatures even without the HRV commissioned. There has been no need for any additional heating for workers onsite throughout the winter of 2014 at outdoor temperatures well below 0 degrees Celsius. During the hottest days of the summer of 2014, the house maintained a comfortable temperature; the geometry of the roof overhangs provided adequate shading from the summer sun to prevent overheating. The indoor environment is also reported to be remarkably quiet.

In this Northern region of the province, access to building materials and products are limited, inflating costs. Some design ideas that were great from an architectural perspective were not so good from a cost and construction perspective. This incongruency should have been considered at the design stage to mitigate cost escalation. For example, labour costs are so high that a significant amount of money could have been saved by simplifying the roof construction using a truss system over a prefabricated flat roof panel rather than framing a cold roof over a vaulted thermal roof panel. Another example was the extremely high costs of procuring a crane on-site. This has implications on the cost benefits of using prefabricated panels. All of these lessons will be passed on to local builders in a construction manual.

As the project nears completion, the City's Energy Manager and visionary behind this project has said goodbye to Fort St. John and moved on to another position in Alberta. This has been a loss for the City but he leaves behind the groundwork for a bright passivhaus future. This type of municipal leadership that we were fortunate to witness can go a long way towards changing the type of building that happens in our communities. Instead of writing green building guidelines and bylaws, the City of Fort St. John chose the more difficult path of implementing an actual project. We will continue to watch with interest to see what the project impacts will be in the future and whether the City of Fort St. John is able to leverage their efforts in creating this small house to have a larger impact on transforming the local building community.

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Zero Energy Solar-House Model for Isolated and Environmental Protection Areas in Brazil

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ABSTRACT

This study aims to analyze the benefits of applying a Zero Energy Building (ZEB) as an alternative to conventional buildings in isolated and environmental protected areas in Brazil as a hosting unit. A Zero Energy Solar-House (ZESH) is defined, considering its fabrication, assembly systems, use of natural resources and strategies for energy efficiency, leading to low environmental impact. A Brazilian scenery is described regarding energy feeding conditions in isolated areas, the occupation of protection areas, which are coveted by real estate market and touristic exploitation, and the consequent environmental impact. The ZESH harnesses sun's energy throughout a photovoltaic (PV) system for energy generation, solar collectors for water heating and passive environmental conditioning. Besides, it has local wastewater treatment and solid waste management systems, reducing the environmental impact arising from the occupants activities. To verify the ZESH model, this study takes the Ekó House Project, an efficient solar house prototype that meets the ZESH premises. This study results in accounting greenhouse gases (GHG) emissions reduction by the solar PV electricity generation instead of diesel generators. Results point out a potential to avoid up to 14.4 t of CO_2/year for one ZESH unit. It is observed that the ZESH contributes to enable the occupation of these areas by local communities or touristic exploitation with responsibility, low resources consumption and reducing the environmental impact when compared to conventional buildings, allowing these areas to develop on a sustainable way and benefiting local communities.

INTRODUCTION AND APPROACH

Brazil is a country known for its rich biodiversity, a coastline with almost 8000 km long and the world's largest tropical rainforest, the Amazon. Brazil is ranked fifth in the world in relation to territory and is the largest country in both South America and the southern hemisphere. Given the Brazilian territorial dimension, many communities are still living in isolated locations with restricted or no access to infrastructure such as electricity, sanitation, transport, health and education. To obtain minimum comfort conditions, these communities rely on isolated systems, when possible, mostly through diesel generators, which are very expensive, cause environmental impacts and affect population's health (Di Lascio, 2009). Furthermore, the lack of infrastructure for sewage treatment and solid waste management also cause environmental impacts such as contamination of soil and water courses (UNEP/UNWTO, 2005).

Besides the demand and impact of the native populations living in isolated areas, often these sites are targeted and exploited by tourism sector, which often causes similar impacts in environmentally sensitive areas. Some negative impacts can be associated with tourism, such as disordered development or inappropriate tourism scale to the area, causing degradation of the resource base and ecosystems; increasing pressure on the natural environment, with degradation or destruction of fragile ecosystems; impacts resulting from the implementation of roads, sanitation, airports, urbanization, and centers for final disposal of solid waste, that could cause negative environmental and social impacts (Brasil, 2009).

On the other hand, there are also positive impacts of tourism activities in isolated and environmental protection areas. Examples include the diversification of economic activities, employment generation and income for local communities; improvement in sanitation; proper handling and disposal of solid waste; improvement in water quality in water bodies and aquifers due to the installation of domestic wastewater treatment systems; possibility of expanding educational and environmental awareness programs (Brasil, 2009).

Many of mentioned impacts, positive and negative, have a direct correlation with the buildings for housing and lodging in remote locations and environmental protection areas. Thus, this study aims to analyze the contribution of a Zero Energy Solar-House (ZESH) model to reduce environmental impacts and improve the quality of life of local populations and in touristic areas, analyzing how architecture can respond to a demand for social and economic development with low environmental impact.

OCCUPATION AND ENERGY ACCESS IN ISOLATED AREAS IN BRAZIL

In Brazil the electric energy is provided almost entirely by the National Interconnected System - SIN a large hydrothermal system, with a strong predominance of hydroelectric plants. Only 3.4% of the country's electricity production capacity is out of SIN (ONS, 2013) mainly in small isolated systems located in the Amazon region. These isolated areas are almost entirely located in the Northern Region and are served by thermal generation (EPE 2013).

The regions without access to electricity are regions where enroll minors Human Development Index - HDI (Di Lascio, 2009). The lack of access to electricity limits the access of isolated populations to basic infrastructure. The power supply from the diesel is often unfeasible economically. With an intense demand for energy, the cost to universalize regions such as the Amazon under the current model, which is based in isolated fossil fuel thermal systems, supported by a strong allowance, can be very costly to the country. The cost of power generation from existing generation systems is made possible by the Fuel Consumption Account - CCC, which in 2006 reached R$ 4.5 billion, approximately 25% greater than the amount of R $ 3.6 billion approved for 2005 (Gonzalez, 2008). Is worth point out that in remote villages, away from the distribution grids, there is only power when the community itself manages a generator and a mini grid, with no public electricity service. Moreover, the diesel to power these engines is usually acquired at a very high price from traders (Di Lascio, 2009).

Besides the issue of economic viability, the diesel generators impact the health of communities supplied by this fuel. In many isolated communities lamps fueled by diesel oil or kerosene are used. This alternative, in addition to being inefficient (7.3 diesel lamps are needed to obtain the same luminance of a 9 watts compact fluorescent lamp) causes respiratory and ophthalmic diseases (Di Lascio, 2009).

The alternative of using overhead transmission and sub-transmission lines has a high rate of acceptance by planners. However, when observing the regional reality, is possible to realize that this type of infrastructure is too costly, or even ecologically unsustainable for many isolated areas (Di Lascio, 2009).

In Brazil, the Light for All (Luz para Todos) program was launched by the Federal Government in 2003 with the challenge of ending the electricity exclusion in the country and bring access to electricity to more than 10 million people (Programa Luz para Todos, 2009). In places where the electricity arrives, the population acquire consumer goods that they could not have when was relying on diesel generators.

Among those appliances, most families buy televisors, refrigerators, blenders and water pumps (Seo, L. M.; Esteves, J. R., 2010. This also encourages these communities to diversify its economy. Some residents are opening their own business, sometimes associated with tourist activities, such as small hotels or restaurants. The access to electricity also favors public facilities such as health centers and schools, improving the quality of life of these communities, allowing an improvement in healthcare services, education and digital inclusion (Seo, L. M.; Esteves, J. R., 2010).

Many are the benefits obtained through the access to electricity. Thus, it is important to notice the suppressed demand for electricity in isolated areas and the importance of adopting energy efficiency measures together with the electricity access.

TOURISM IN ISOLATED AREAS

Considering initially mentioned positive influences that tourism can have on isolated areas, this study assumes the possibility to integrate environmental tourism activities with the native communities of such areas, collaboratively, looking toward a benefit to both parties. Naturally, this can only happen through a sustainable tourism way, which is the “tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities” (UNEP/UNWTO, 2005).

UNEP points out that tourism has the potential to contribute to local communities, especially the poor, through the development of local economy. The extent of the direct benefits to communities depend in large part on the percentage of tourism needs that are offered onsite, as product, labor, tourism services, and, increasingly, the "green services" on energy efficiency and water and waste management. UNEP also shows that over a third of travelers are in favor of eco-tourism and are willing to pay between 2% and 40% more for this experience. Tourists are interested in relevant social, cultural and environmental issues for the destinations they visit, and are interested in supporting hotels committed to protecting the local environment (UNEP, 2011).

Programs of the Ministry of Tourism in Brazil define indicators of environmental sustainability for tourism in the country, this study assumes as relevant for a ZESH hosting unit the following indicators: water and energy consumption per guest, waste generation per guest and the percentage of solid waste recycled or sent to composting (Brasil, 2007). Furthermore, it is important to highlight the potential that such tourism development may represent with regard to education and environmental awareness, influencing its audience to adopt different habits to reduce consumption of natural resources and environmental impacts (Projeto Ekó House, 2012).

It is noticeable that the global tourism economy represents 5% of the Gross Domestic Product (GDP) and accounts for about 8% of total employment (UNEP, 2011). It is expected that the "greening" of tourism contribute to improvements in energy efficiency, water and waste systems, and enhance the potential for job creation in the sector with greater hiring and prospecting site and significant opportunities in tourism oriented to the local culture and the natural environment (UNEP, 2011). Thus, this study works with a scenario in which tourism projects focused on isolated and environmentally sensitive areas are developed along with local communities, promoting economic and social development, improving quality of life in an environmentally sustainable manner.

POTENTIAL OF SOLAR ENERGY IN BRAZIL

Brazil has favorable conditions for harnessing solar energy. Average annual irradiation varies between 1.200 e 2.400kWh/m^2/year, values that are significantly higher than most European countries. As shown in **Figure 1**, the higher irradiation areas are the areas 5 to 8, in which the average productivity varies between 1.260 e 1.420Wh/Wp/year (EPE, 2012).

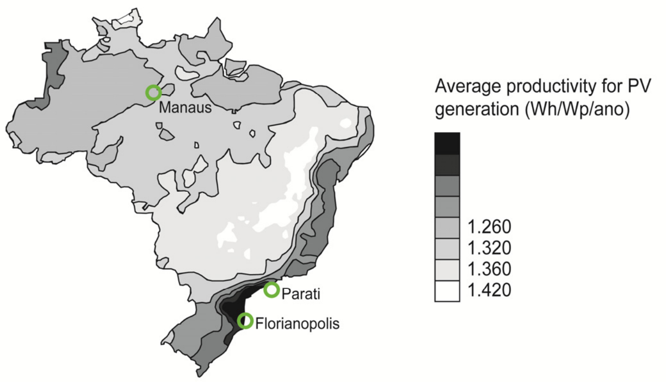


Figure 1 Solar irradiation in Brazil. (EPE, 2012)

In addition to this, in locations without conventional electric service, photovoltaic (PV) systems constitute a viable alternative when compared with the extension of the power grid, diesel generation and other sources (Pinho, 2008). The problem lies in the economic conditions of people living in these isolated areas that cannot afford such systems. However, some kinds of subsidies may contribute on economic viability of PV systems in Brazil, such as reducing taxes on industrialized products, discount on income tax, specific lines of credit (EPE, 2012). Besides, the same way the government subsidizes diesel, subsidy for PV systems could increase, given the social and environmental benefits by the use of PV as an alternative to diesel. Subsidies could also be associated with sustainable tourism development.

ZERO ENERGY SOLAR-HOUSE BASED ON EKÓ HOUSE PROTOTYPE

A Zero Energy Building **-** ZEB is defined as a building that produces, through local sources – and preferably renewable ones – the energy it consumes, considering an annual balance (Torcellini et al, 2006). The ZESH modeled for this study integrates several systems to ensure its operation and functionality, comfort for the occupants, and low environmental impact. To verify this ZESH model it is adopted the Ekó House prototype. This prototype was developed by Team Brasil, a partnership between University of São Paulo and Federal University of Santa Catarina, and represented Brazil in Solar Decathlon Europe 2012 competition, held in Madrid.

Ekó House is taken as reference for this study because it meets the guidelines of a ZESH. In addition, the specific purpose for which the prototype was conceived is hosting in isolated environmentally sensitive areas in Brazil. The prototype can be connected to a local grid and could export the surplus energy to meet the demand of local facilities, like schools and healthy centers, or dwellings in these isolated locations. The ZESH strategies and systems are presented below.

Solar trajectory and orientation

The ZESH adopts a geometry that results in elongated facades facing north and south orientation, in order to obtain a better use of the sun throughout the year. In summer, when the sun is more directly overhead, radiation is less intense on north oriented facades than is east and west oriented facades (Southern Hemisphere). In winter the sun is lower, and radiation is more intense in north oriented facades than in east and west oriented facades, as shown in **Figure 2**. North oriented facades receive more direct solar gains in winter and less in summer than other facades.

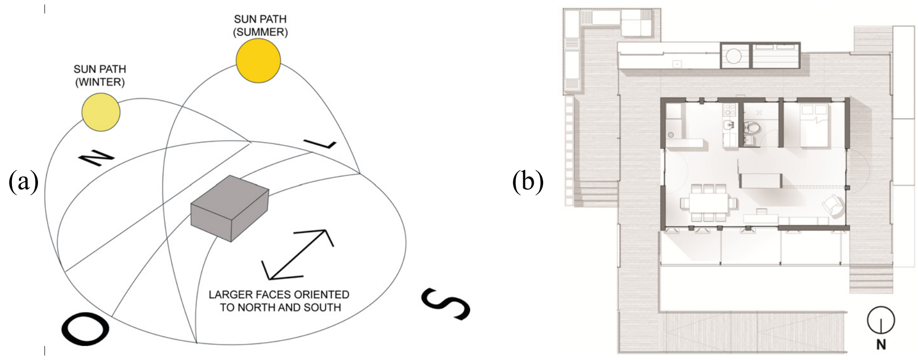


Figure 2 (a) Solar trajectory and (b) building geometry. (Projeto Ekó House, 2012)

Building envelope

Many strategies are possible to achieve environmental conditioning. The envelope elements of a ZESH have appropriate thermal performance, based on climate conditions of the location, through strategies such as insulation, the use of thermal mass and/or natural ventilation, among others. The Ekó House prototype has high thermal insulation levels and windows properly dimensioned and positioned, ensuring natural lighting and ventilation. This results in good comfort conditions with low energy consumption by integrating passive and active strategies. Simulation models indicate a Daylight Autonomy of 60% for the Ekó House prototype (Projeto Ekó House, 2012).

However, the climatic conditions vary widely, as well as the solutions to adapt the buildings to each climate. Considering this, a pre-fabricated structure made of modular panels is proposed to enables the use of different materials and, therefore, different strategies to the envelope, allowing an adaptation of the ZESH to different needs and conditions. Besides, the use of wooden pre-fabricated structural panels allows faster and cleaner assembly when compared to conventional constructions. **Figure 3** shows this modular construction system.

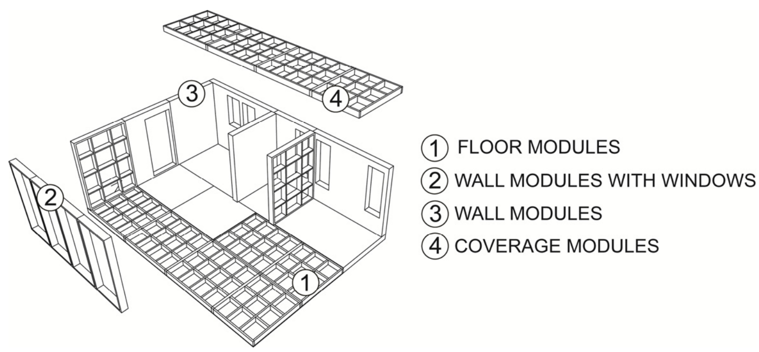


Figure 3 Modular system of a ZESH. (Projeto Ekó House, 2012)

Management and treatment of waste and sewage

Domestic waste, when correctly managed, can reduce significantly the volume of rejects to be discarded. Specific compartments for waste disposal can be integrated in the house design, both inside (for dry waste) and outside (composter). Adequate space for waste storage and organic material composting are essential and help the occupants to dispose wastes correctly.

In a ZESH there is a concern with the proper treatment and disposal of wastewater. Ekó House sewer system is decentralized. A composting toilet, which requires no water, is adopted. This technology accelerates the composting process to avoid odors and contribute to reduce fresh-water consumption (Projeto Ekó House, 2012). Through this system, it is possible to obtain an organic compound free of contaminants, avoiding the need for larger scale systems for treating such waste. The wastewater from shower, sink and washing machine, kitchen sink and dishwasher is treated by a natural system planted with hybrid filters macrophytes (wetlands). After this process the water can return to the environment without harming nature (Projeto Ekó House, 2012). Through such systems consumption of potable water is reduced. Furthermore, there is a system for collecting rainwater, which can be used as non-potable water or even be treated and consumed. **Figure 4** illustrates such systems.

(a) 

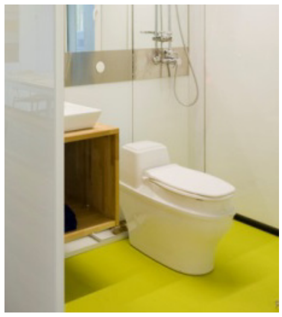
(b) 

Figure 4 (a) Systems for waste treatment and (b) composting toilet. (Projeto Ekó House, 2012)

Such systems for solid waste and wastewater management may waive the installation of large infrastructure for such purposes, and contribute to avoid contamination of soil and water bodies in areas where such infrastructure is often unfeasible.

Structure for solar systems

Architectural integration of solar system into ZESH is supposed to enable the profitable and advantageous use of solar energy into good quality architectural design. The architectural design can influence the performance of solar systems, allowing its integration into the envelope faces with higher levels of solar radiation and the proper arrangement of the system.

In Ekó House prototype, the roof surface is the suitable area for installing PV array due to its advantageous irradiation, is the face that gets higher incidence of radiation throughout the year, so it was used for the installation of solar systems. An aluminum frame, fastened to zipped metallic tiles supports PV systems and solar collectors. This structure is oriented to the North (considering the location in Brazil) and can be adjusted at different angles (10°, 15°, 20°, 25° and 30°). This ensures the efficiency of solar systems throughout the year and in different regions of the country, as shown in **Figure 5**.

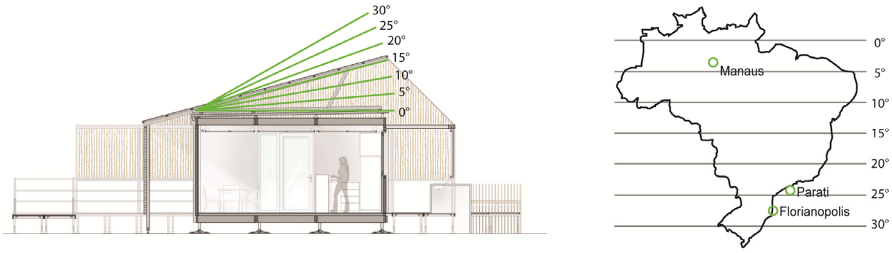


Figure 5 Structure for solar systems in the Ekó House prototype and adaptability to different Brazilian latitudes. (DIAS, 2014)

Water heating system

Heat water demand is associated to bathing, home appliances and in the thermal conditioning. Solar radiation can be harnessed to meet this demand in a ZESH. Solar collectors can be applied associated with electric shower, gas heating, electric boiler, among others. Flat plate solar collectors and evacuated tubes systems are examples of widely used collectors. The Ekó House prototype has four u-pipe solar collector (evacuated tubes) ensuring a high efficiency system.

The fastening system shall also be suitable to the envelope and it is important to provide appropriate space for reservoirs, passing pipes, and integration with other heating systems. Access for maintenance is also essential to ensure system performance.

PV Solar System

The solar PV generation on single houses can happen in two ways: with a system interconnected to the grid; or through a standalone system, and a storage system and/or additional generation is needed to ensure system's energy security. For the ZESH hosting unit is considered the adoption of a photovoltaic system associated to a battery bank and diesel generator set. It is important to notice that, in Brazil, the use of alternative fuels for electricity generation in autonomous systems has increased, as the use of biodiesel (Gonzalez, 2008) and even experimental processes such as gasification from the seed of the acai berry, which has a cost three times less than the cost of diesel per kWh generated (Freitas, 2006). Thus, it is possible to have a system that complements photovoltaic generation with a lower environmental impact.

The Ekó House prototype comprises 48 monocrystalline PV panels, with an 18.5% efficiency and 11 kWp of total installed capacity. Considering the location in Madrid, the PV system generates, on average, 1.790kWh/month, enough to meet the prototype energy demand, which is around 735 kWh/month, and still provide around 1.055kWh/month of clean energy to the grid (Projeto Ekó House, 2012).

In a ZESH the architectural design must contribute to a higher efficiency of the system, ensuring that PV modules are arranged on the sides of the envelope with better solar radiation, or even through the use of devices which adjust the tilt or track the sun, adapting the PV system for the orientation throughout the day and the year. Moreover, the architectural design should also provide suitable and safe conditions to place other equipment forming part of the solar PV system, as inverters spaces, in addition to providing space and appropriate protections for electrical wiring, terminals, fuses and circuit breakers. Cleaning and maintenance of the modules shall also be considered in the architectural design to ensure the best system performance throughout its lifetime. (Projeto Ekó House, 2012). ZESH solar systems are exemplified in **Figure 6**.

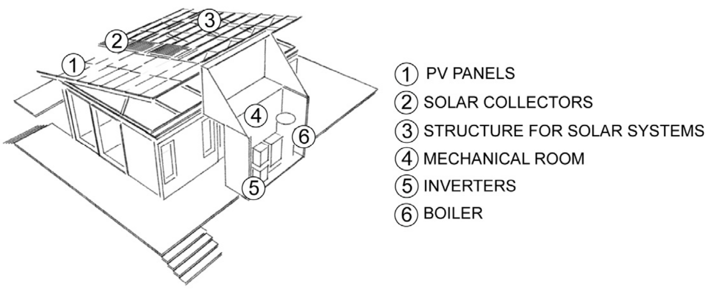


Figure 6 Solar systems for a ZESH. (Projeto Ekó House, 2012)

The strategies adopted in ZESH confer a degree of adaptability, allowing the model to meet different demands. The full model, including all of its systems, responds to comfort standards of developed countries. However, the modular system allows beginning with the most basic systems to lower cost, and then install systems and expand square footage by attaching new modules. This modularity also provides flexibility in the final occupation, and this model can meet the demand for housing by local communities or units for hosting tourists.

ENERGY CONSUMPTION IN A ZESH

The data presented here are from the Ekó House prototype, which are fundamentally derived from computer simulations to estimate values of energy generation and consumption by this prototype over a year of operation. The energy consumption considers the prototype in Madrid. Is worth remembering that this prototype was designed to meet the standards for the use and comfort at developed countries due to the participation in the international competition Solar Decathlon Europe 2012. The project has been conditioned by the rules and requirements and does not represent the standard of living of the largest part of Brazilian population, especially those living in isolated areas. Thus, it is possible to assume that the Ekó House average consumption, of 735 kWh/month, represents a situation of highest level of electricity consumption, even for hosting units in Brazil.

The energy generation was simulated on RETScreen® 4 software and consider both the prototype in Madrid and in some places in Brazil with potential to apply the prototype as a hosting unit in isolated areas. The PV system is the same of the prototype in all places, with 11 kWp. The slope and orientation of the system are changed in order to achieve better efficiency of the system for each location. These places are Manaus, in the Amazon region; Parati, touristic place located near Rio de Janeiro with some isolated communities; and Florianopolis, which is an island with some few isolated spots and less favorable solar radiation levels along Brazilian territory. **Figure 7** brings energy balance data for the Ekó House prototype.

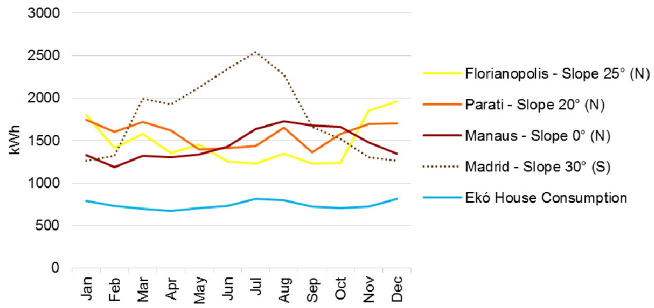


Figure 7 Ekó House energy balance considering different locations for energy generation. (Projeto Ekó House, 2012; RETScreen® 4)

It is possible to observe that even with a consumption that reflects standards of developed countries, the prototype proves more efficiency than homes in countries like the U.S., where the average consumption is 903 kWh/month for each residence (EIA, 2012). Besides, the PV system has a positive balance throughout the year. In addition, the modular structure favors the adoption of different materials for the envelope. This enables an adaptation to the climate of each region, providing appropriate comfort with lower energy consumption

Regarding GHG emissions associated to energy generation, the emission factor for diesel oil generator set is 808 g CO_2/kWh (IPCC, 2007). When properly maintained, the generators have normal efficiency of 350 g/kWh, but most groups used in isolated areas in Brazil receives no adequate maintenance, increasing fuel consumption for about 500 g/kWh (Di Lascio, 2009). For the PV systems it is applied an average emission factor of 46 g CO_2/kWh (IPCC, 2012). Thus, avoided emissions by generating energy through PV system instead of diesel would be 762 g CO_2/kWh.

The table and graph in **Figure 8** demonstrate energy generation and avoided emissions for one year of operation of a ZESH. It is worth noting that even a high energy consumption situation is compensated by the use of a clean source. Besides, the more efficient is the electricity consumption in ZESH units, more clean energy can be shared with local communities.

(a)

	PV Generation (kWh)	Energy Consumption (kWh)	PV Surplus Energy (kWh)
Florianopolis	17696	8820	8876
Parati	18910	8820	10090
Manaus	17411	8820	8591

(b)

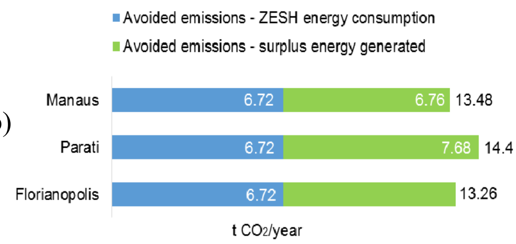


Figure 8 (a) Energy generation and (b) avoided emissions for one year of operation of a ZESH.

CONCLUSION

This study concludes that ZESH demonstrated and verified by the Ekó House prototype represents an alternative to enable the occupation in remote and environmentally sensitive areas with low environmental impact, promoting access of local communities to a basic and autonomous infrastructure that can contribute to its socioeconomic development. This ZESH can be adopted both by local people and by tourist developments. It is a model that responds positively to environmental indicators set by the Brazilian government and to the concept of sustainable tourism defined by UNWTO.

The solutions proposed for this ZESH model, demonstrate the important role of architecture with regard to the use of the sun, both associated with passive strategies for greater energy efficiency, and for obtaining energy through active systems such as PV and water heating systems. In this way, it is possible to maintain comfortable levels for occupants without necessarily increasing energy consumption. The prototype also demonstrates that it is possible to associate to a housing unit some systems that ensure access to basic infrastructure for sewage treatment and solid waste, avoiding contamination of soil and water, and providing healthy and hygienic conditions for local and tourist populations.

Finally, the ZESH model presented in this study can be adopted and contribute to the mitigation of global warming by reducing GHG emissions, to an improvement in the quality of life of local populations in remote areas, to develop tourism in a sustainable way in environmentally sensitive areas, to promote socioeconomic development in remote communities, and also to educate different audiences (local and visitors) about how some appropriate systems and habits can reduce the impact of human activities on the environment.

ACKNOWLEDGMENTS

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Development of Single Parameter to Rate Architectural Design for Green Building Certifications

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ABSTRACT

India is witnessing green building revolution. With rating schemes like LEED, IGBC and GRIHA in place and practice, building stakeholders are becoming more aware of sustainability issues. Issues under sustainability are clubbed under - Site, Energy, Water, Waste and materials and Environment. For most rating schemes across the world, Energy carries maximum number of points. High importance has been placed on energy because of current world energy scenario. Buildings are assuming critical role in energy dynamics. In India, building construction is taking place at a much higher rate than usual. Buildings consume tremendous amount of energy and this rate of energy consumption in buildings is also increasing. As per rating schemes, a comparison of energy consumption with base case or even an absolute figure of energy consumption is considered for ranking the energy efficiency of building. However, our traditional vernacular systems and passive features of building and design which impacted thermal comfort in response to climate are not accounted for in judgment criteria. At no place is the thermal comfort creation though spatial planning is emphasized, encouraged and rated. Therefore, in today's time when relevance of energy efficiency is far larger than earlier, it becomes imperative that thermal comfort be achieved through spatial planning and efficiency of spatial planning be made judgment criteria for rating sustainability quotient of a building. Hence a common parameter needs to be evolved to quantify and judge achievement of thermal comfort through spatial planning and passive techniques in any building across the globe in context to the climate in which building is placed. This research is aimed at development of such parameter and its applicability in rating schemes. The paper details out the parameter, methodology to calculate it for any building and its relevance for building sustainability.

INTRODUCTION

India is a developing economy and building construction industry contributes substantially towards GDP, resource consumption, energy demand and pollution. (Tiwari P, 2001) Buildings therefore need to be constructed in a manner that they have least negative impact on the environment and maximize health and other benefits. (Arif M et. al, 2009) This fact has been duly recognized and that is the reason we have two successful Green Building Rating systems in our country – LEED-IGBC and GRIHA. (igbc.in, grihaindia.org)) Both these rating systems are more or less similar to many other existing systems in the world. A green building is evaluated based upon certain themes which are almost the same; while weightage of themes vary from one system to other. (Fowler K M et al, 2006) A comparative study has been done and the themes which are evaluated are- Site and transport, Energy, Indoor Environment, Materials and waste, Water and Operations and maintenance. (Liu G, 2010) Figure 1 clearly shows that maximum emphasis is laid on energy efficiency.

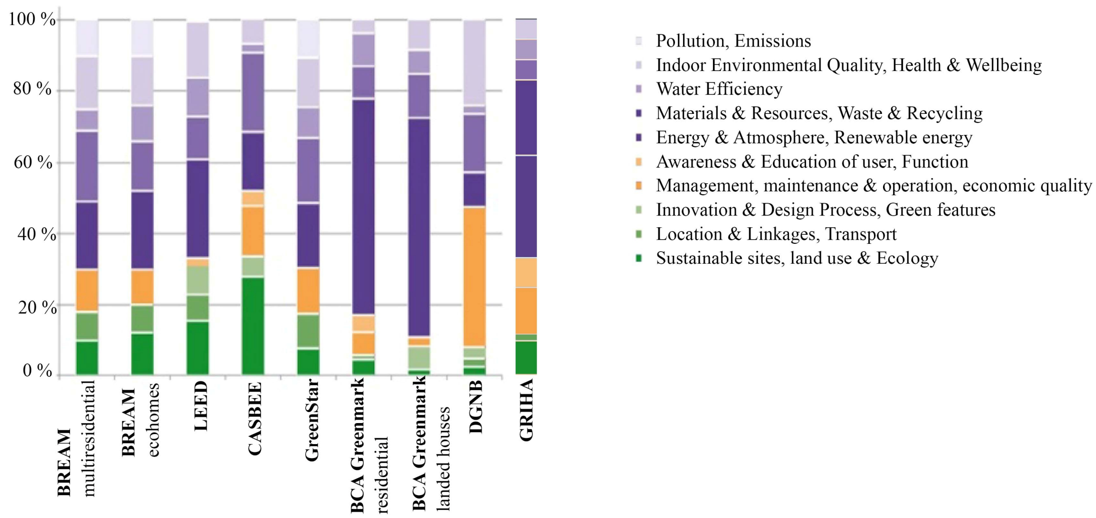


Figure 1 Comparative Chart Showing Weightage of Different Themes in Different Rating Systems across the World

While credits are given for innovation and design, quantitative assessment of design for achieving energy efficiency doesn't feature anywhere.(Happio A, 2008) For achieving a desired energy performance (whether prescriptive path is followed or performance rating method is followed) heads which are considered are- Building envelope, HVAC, Service Water Heating, Power, Lighting and other equipments. Building envelope focuses on Building Orientation, WWR, Fenestration design, type of glass being selected and opaque assemblies. (Fowler K M et al, 2006; Ballinger J A,1988) Once mandatory requirements have been fulfilled, overall reduction in energy consumption is calculated and credits awarded. In all this, capability of architectural spatial planning in bringing in substantial reduction to energy consumption has totally been ignored. (Cole R J, 2012) It is like creating a problem through design and then solving it through employing better systems. The issue becomes more important for a country like India where we have a variety of climates. (ECBC, 2007) All our vernacular buildings present efficient examples where only with the help of spatial planning and materials (building envelope), thermally comfortable indoor environments have been created. This approach is a preventive approach and also affects the stakeholder behavior.(Plessis C et al, 2011) The need here is to develop a parameter by which we can judge the effectiveness of any architectural design in any climatic context (normalization) in bringing in energy efficiency.(Haas R, 1997)

THE CHALLENGE

Aim of this research is to develop a tool by which effectiveness of an architectural design in bringing in thermal comfort (which leads to energy efficiency) can be evaluated using a single parameter.

Taking a look at how energy efficiency of a project is determined through whole building simulation. A base case is established as per a standard document or code; say ASHRAE 90.1 in case of LEED or energy consumption baseline in case of GRIHA. (ASHRAE 90.1, ; ECBC, 2007) Architectural design remains same for base case and proposed case. Energy Conservation Measures (ECM's) are then added to proposed case (which mainly comprise of alternatives of building construction/ building envelope and mechanical systems) and performance of building is evaluated. In this entire process, potential of a better spatial design's contribution towards energy efficiency is not being judged. Now if comparison of architectural design is to be done, what can be the base case? Since each building should respond to climate in which it is placed, the tool must have a tangible parameter through which effectiveness of architectural design can be evaluated.

SOLUTION FINDING

For evaluating effectiveness of architectural design towards creation of thermal comfort leading to energy efficiency, first solution that strikes is the use of thermal comfort indices for judging whether the design will be able to bring in thermal comfort.

Existing attempts

There are many thermal comfort indices which have been developed. To count a few popular ones- Effective Temperature, Corrected Effective Temperature, Operative Temperature, Equatorial Comfort Index, Bioclimatic Chart, Fanger's PMV, Tropical Summer Index etc. (Koenigsberger et al, 1973). Each whole building simulation program is capable of generating thermal comfort data usually based upon PMV.But there are some problems with this assessment as it is not a clear indication of efficiency of architectural design-

1. The building design which is simulated includes all mechanical, electrical and other systems of thermal comfort creation. Thus a impact of only space design cannot be seen.
2. Even if simulation is intended to be done only for building (devoid of any mechanical/electrical installation), the results can be deceptive. For example in case of a building situated in a temperate climate like Bangalore; it would have more hours falling under comfort range as compared to a building (though efficiently designed) in an extreme climate like Jaisalmer.

Besides using thermal comfort indices, another factor called Degree Days is also being used. But Degree Days help to normalize the weather variation which are used for simulation rather than normalizing the building's response to a climate.(Eto J H, 1988)

Thus the issue is of normalization of building's response to weather because a robust green building rating system has to be applicable to any part of the world. Hence thermal comfort indices cannot be used directly for assessing the effectiveness of space design for green building rating. A lot of efforts towards weather normalization has been made world wide. The prime objective however was to normalize weather to normalize variations in weather. The PRInceton Scorekeeping Method (PRISM)' which was initially created for calculating changes in energy consumption in a group of heated houses without cooling to individual houses (M. F. Fels et al. 1986), was developed to calculate energy consumption for individual house's cooling and heating without integrating the two (C. L. Reynolds et al 1988). PRISM considers weather conditions as an important parameter while calculating energy consumption but does not regard architectural design as a parameter. Building Energy Analysis Consultant (BEACON) system was developed by Haberl et al (1988), which is capable of continuously monitoring and diagnosing the operation and maintenance problems identifying the causes of abnormal energy consumption. In most of the models it is considered that energy use in any other year is simply the product of the appropriate degree-days in this other year and the weather-invariant parameters (Joseph H. Eto, 1988). So, Joseph H. Eto (1988) developed a simulation model which accounts for temperature forecasting based on weather conditions of a decade. Radu Zmeureanu (1992) presented a new method for weather-normalization to be used for energy consumed from all types of energy sources and considers weather as a factor contributing to energy consumption but lacks consideration of architectural design.

None of the weather normalization techniques discuss the impact of architectural design on thermal comfort normalized to the weather to which building is exposed. Hence a tool/parameter needs to be developed to evaluate thermal performance of building in response to climate it is being subjected to.

THE PARAMETER

The parameter uses Tropical Summer Index as the selected thermal comfort index for assessing thermal comfort creation. TSI has been chosen as the parameter is initially developed to respond to Indian subcontinent and TSI is the accepted thermal comfort index in National Building Code. The parameter is based upon the ability of building to convert uncomfortable hours outside in a selected climate into comfortable hours inside. Similar attempt (not to create a parameter but in approach) was made to compare passively designed office buildings in Germany. (Jens U et al, 2007) More is the number of such hours, more is the efficiency of design. Also the design has to be able to retain outdoor thermal comfort (when possible) inside the building.

Tropical Summer Index (Sharma M R, 1986; SP 41; SP 07)

TSI is defined as "the temperature of calm air, at 50 percent relative humidity which imparts the same thermal sensation as the given environment." The 50 percent level of relative humidity is chosen for this index as it is a reasonable intermediate value for the prevailing humidity conditions."

Mathematically, TSI (°C) is expressed as

$$TSI = 0.308T_w + 0.745T_g - 2.06\sqrt{V + 0.841} \quad (1)$$

Tw = Wet Bulb temperature in ° C, Tg = Globe Temperature in ° C, V = Air Velocity in m/s

For indoors, Globe temperature can be replaced with Dry-Bulb temperature. It is because Globe temperature takes into account Dry-Bulb temperature as well as effect of direct radiation also. Thus in the absence of radiation, globe temperature is almost the same as DBT. The environment was found comfortable between 25 to 30 TSI. It was tolerable up to 34 and down to 19. Lesser than 19, it was considered as too cold and beyond 34 it was considered as too hot. The TSI decreases further with increase in air velocity. (Table 1)

Table 1Decrease in TSI with Increase in Air Velocity

Air Velocity m/s	Decrease in TSI in ° C
0.5	1.4
1.0	2.0
1.5	2.5
2.0	2.8
2.5	3.2

THE PARAMETER – DUHOI

DUHOI – Difference in Uncomfortable Hours Outside vs Inside. As the title clearly states- parameter is the difference of uncomfortable hours outside against inside in a given climate. The parameter compares thermal comfort achieved inside the building through design and construction to climate outside for all hours in a year. Each building design will have one single value for DUHOI. However DUHOI can be calculated for extreme seasons like summers in hot-dry climate, winters in cold climates depending upon the criticality. Calculation of DUHOI is demonstrated using analysis of hourly data obtained through whole building simulation of a traditional haveli residence in Sikar district of Shekhawati, Rajasthan, India (AgrawalA, 2006). Figure 2 shows typical ground floor plan of the case with open to sky courtyard in the centre and double layered rooms all around. All windows and walls are shaded by sun shades and thick walls are made up of brick set in lime mortar. Haveli is simulated for one year and hourly data (Dry Bulb temperature, Relative Humidity and air velocity inside) thus obtained is used to calculate TSI for all habitable spaces in the Haveli. Air velocity inside could not be obtained through simulation, therefore excel sheet was prepared as per NBC 2007 manually which were further used to calculate TSI. After this DUHOI is calculated in the following manner-

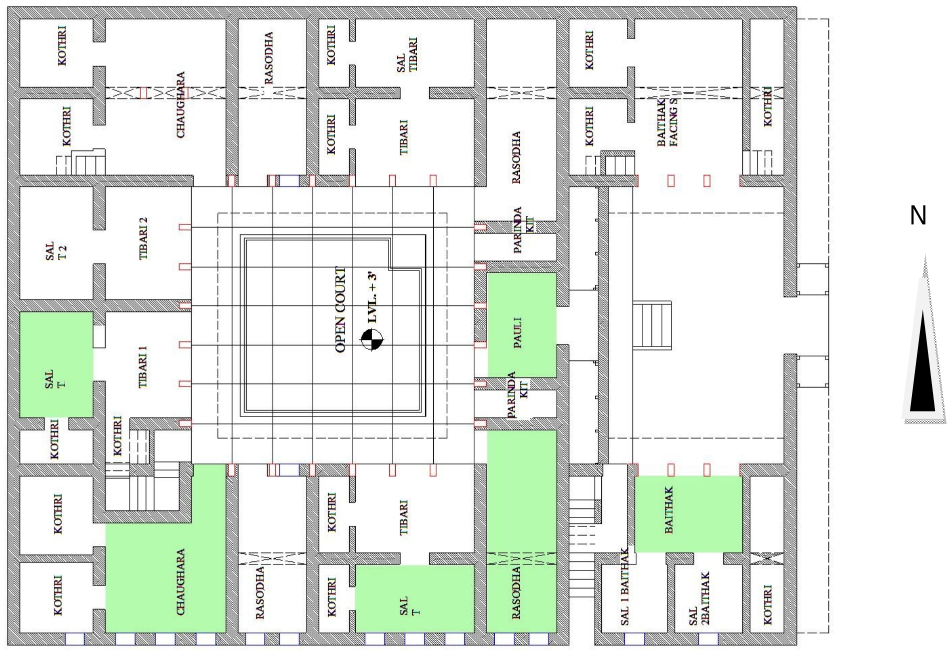


Figure 2 Upper Ground Floor Plan of a typical and Design Builder snapshot of modeled Haveli (Shaded areas are the ones which have ben simulated for calculations)

Methodology

DUHOI is calculated in a step wise manner as follows-

1. Calculate TSI for all habitable spaces and outside weather for entire year and all hours as per the formula of TSI stated above. (Table 2 – Because of limitation of space, calculations for only seven out of nineteen spaces have been demonstrated here)
2. Calculate the difference brought in TSI through design to each space. (When TSI inside is brought towards comfort it is counted as positive; if it is taken away from comfort it is taken as negative; based upon the comfort limits of TSI i.e. 25-30). (Table 3)
3. Overall difference brought in TSI (adding up positive and negative) is then averaged for the number of habitable spaces evaluated and number of hours for which evaluation is done. In case when TSI outside is already in comfort range say 29 and indoor TSI value also falls within comfort range say 25, such values will not be considered for calculations. (Table 3)

Table 2. Table showing Consolidated Thermal Comfort Data (TSI values) of Habitable Spaces in Simulated Haveli for few hours on one Typical Summer Day and TSI values Outside

Time	Baithak	Rasodha	Chaughara	Pauli	Sal 1	Sal T	TSI o
0:00	31.8	32.1	32.1	32.5	31.1	32.6	34.3
1:00	31.6	31.9	31.8	32.2	30.9	32.3	33.6
2:00	31.3	31.6	31.5	32.0	30.6	32.1	32.8
3:00	30.9	31.3	31.2	31.7	30.4	31.8	31.0
4:00	30.7	31.1	30.9	31.5	30.3	31.7	30.2
5:00	30.4	30.9	30.7	31.3	30.1	31.5	29.4
6:00	30.5	31.0	30.8	31.4	30.3	31.6	30.4
7:00	30.9	31.3	31.2	31.7	30.6	32.0	31.2

Table continues for 8760 hours.

Table 3. Table showing Difference of TSI Outdoors Vs Indoors for Uncomfortable Hours Outside

Time	Baithak	Rasodha	Chaughara	Pauli	Sal 1	Sal T
0:00	2.5	2.2	2.2	1.8	3.2	1.7
1:00	2.0	1.7	1.8	1.4	2.7	1.3
2:00	1.5	1.2	1.3	0.8	2.2	0.7
3:00	0.1	-0.3	-0.2	-0.7	0.6	-0.8
4:00	-0.5	-0.9	-0.7	-1.3	-0.1	-1.5
5:00	-1.0	-1.5	-1.3	-1.9	-0.7	-2.1
6:00	0.7	0.2	0.4	-0.2	0.9	-0.4
7:00	0.3	-0.1	0.0	-0.5	0.6	-0.8
	42.0	36.1	36.4	27.7	59.4	24.7

Table continues for 8760 hours.

$$\text{DUHOI} = (\sum dT) \div N*h$$

Where

$\sum dT$ = Summation of difference in TSI values of all habitable spaces to TSI Outside

N = Number of Habitable Spaces Analyzed

H = Number of Hours

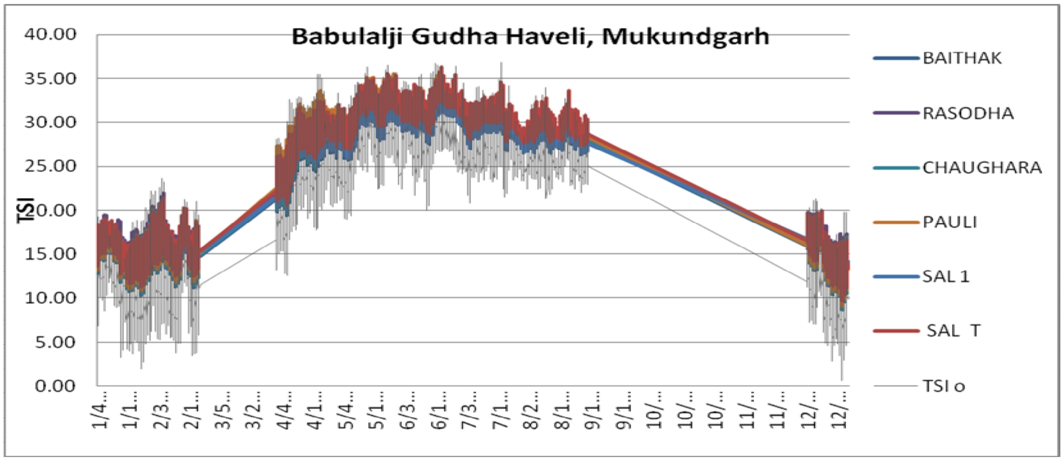
Conditions for calculation of DUHOI

Based upon logics and rationale, certain conditions have been set to calculate DUHOI.

1. Only habitable spaces are accounted for in this calculation. Service and ancillary areas such as circulation, toilets, machine rooms, kitchens etc are not included while calculating TSI and DUHOI.
2. If accessible open spaces have been provided in the building and schedule of activities suggests use of such a space during certain periods of the day, negative TSI difference values for those periods shall not be included in overall calculation of DUHOI. This is done in order to ensure that open spaces have been appropriately used. However for this option to be available, schedule has to be appropriately configured before simulating the building for its thermal comfort performance.
3. Building is assumed to be naturally ventilated without presence of any mechanical/electrical system in place. Natural ventilation schedule as perthe practice of opening windows during summer nights and winter day has been included.
4. Energy consumption for lighting and heat gain due to lighting is neglected for calculation of thermal comfort.
5. In case of large building complexes, such as campuses, mutual shading and local wind pattern of building complex will be accounted for in simulation.

Graph 1 plots hourly thermal comfort data for a Building. It can be seen that building is able to bring about positive changes in environmental conditions. Following the steps mentioned above to calculate DUHOI, difference brought is calculated using formula and the final value of DUHOI for the period simulated is calculated to be 1.41. This implies that building is able to convert uncomfortable hours into comfortable hours inside by 1.41 TSI on an average.

To know the performance of building in different seasons, seasonal DUHOI can also be found out and it can be ascertained that improvements are needed to bring down the temperature or to heat up a space. For the same building simulated here, DUHOI (summer) is 1.99 while DUHOI (Winter) is 1.32. This gives a clear picture that this building performs better in summers as compared to winter.



Graph 1. Graph showing Consolidated Thermal Comfort Data (TSI values) of selected Habitable Spaces in Simulated Haveli for an Year (excluding 3 months of March, half of September, October and Half of November) and TSI values for the same Outside

Advantages

DUHOI is a robust parameter which can be applied to any building in any climate and it has many advantages-

1. The need for a virtual base case has been eliminated. Weather of a place where building is situated acts as the reference and building is supposed to respond to weather only.
2. In this manner, any building situated anywhere in the world can be compared without making comparison of scale of building, typology and systems involved.

Application to Green Building Rating Schemes

Before DUHOI is included in rating schemes as a credit or a prerequisite, extensive base work needs to be carried out. For all climates of India and world, finest examples of passive designing (traditional and contemporary) can be picked up and DUHOI can be calculated for them. Based on this an acceptable range can be set for each climate and credits can be awarded. This would ensure that any building which is intended to be constructed as green building must have an architectural design which responds to climate of the place unlike current scenario. This way, newer green buildings based on DUHOI parameter will look local and respond appropriately to climate.

CONCLUSION

DUHOI is a robust and universal parameter which can be applied to green building rating systems. This would help in utilizing full potential of architects in making green buildings which would respond to climate as the first step towards building green. This move will have substantial effect in reducing energy consumption by buildings throughout the world.

GLOSSARY OF HINDI WORDS

Haveli	– Traditional courtyard type residence	Baithak	- Living room
Chaughara	- Largest bedroom in the corner of house	Rasodha	- Kitchen
Pauli	- Transition space from outer court to inner court	Sal	- Bedroom/ Room

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Towards new design tools for integrating environmental criteria in the design process of architectural and urban projects in developing countries

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ABSTRACT

Cities are complex systems rapidly evolving in a context of strong interweaving between problems and solutions especially in developing countries. The architectural design and the city management processes are renewed by the eruption of sustainable development. These processes are multi-scale: new geographical, temporal and political scales are emerging, calling for new tools for monitoring architectural and urban environmental changes, for implementing comprehensive plans, or for communicating between practitioners. Number of communities in developing countries has taken initiatives to develop tools based on sets of sustainability indicators. But are these tools really helpful during the architectural design or the urban management processes characterized by complexity, fussy or lacunar data, various time and space scales and multi-actors decisions? We will demonstrate in this paper, that these systems, aiming at "a posteriori" diagnosis, cannot be used directly during these fuzzy processes, especially during their early phases very critical with respect to solutions. By adjoining them multicriteria decision support techniques, they may become powerful tools for decision support. Architectural and urban designs may be evaluated using a set of weighted environmental criteria and methods to aggregate the various dimensions involved. Some Electre methods based on the comparison between pairs of solutions have been successfully used in that sense. A step further away may be performed from decision to evaluation support tools, by comparing ongoing urban designs against convolutions of systems of practitioners' values. This "value focused" approach, combined with the Electre-Tri method has been successfully integrated for evaluating the performance of urban projects, according to their distance to various user-defined systems of values.

INTRODUCTION

The urban development is characterized by various changes and mutations. The environmental impacts of urban designs may be numerous, diverse and sometimes conflicting. The magnitude of the relationship between these different impacts shows potential dangers from decisions related to a family of impacts: solving a problem often creates another.

In this context, a large number of communities have taken initiatives to develop a new understanding of how urban systems work and how they interact with their environment. These tools are mostly based on sets of sustainability indicators (Mori 2012). They are supposed to help urban practitioners to design and to implement comprehensive plans (Alberti, 1996; Briassoulis, 2001; Brandon, 2005). At the same time, specific international programs have been created to develop and

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harmonize urban indicators worldwide, such as UNCSD (Stiglitz, 2009), OECD (OECD, 2011), (UNU, 2012).

Simultaneously, the urban decision is renewed by the eruption of sustainable development, and virtually all communities share concerns for the state of their environment.

The architectural design and urban planning processes are critical to global sustainability, but there is no consensus on how to model this sustainability (Owens 1986; Newman and Kenworthy 1989; Adolphe 1995; Tanguay, 2010). During these processes, practitioners are looking for solutions based on “reasonable compromise” between non-homogenous constraints instead of collecting optimal but partial answers: a new culture of the consensus that aims at "un-optimizing" urban decisions.

A rising information level characterizes this process. In the early stages, the information available is low because it is impossible to apply straightfully all the constraints: design is a wicked problem (Conklin, 2005). Indeed, the early design stages of these processes have a hegemonic weight related with fundamental architecture, urban and technical choices. At the beginning of the process, the importance of design choices is maximum; at the end, it is minimum. This context of problem solving has been baptized “the paradox of the architectural or urban design process” (Adolphe, 1995) - see figure1.

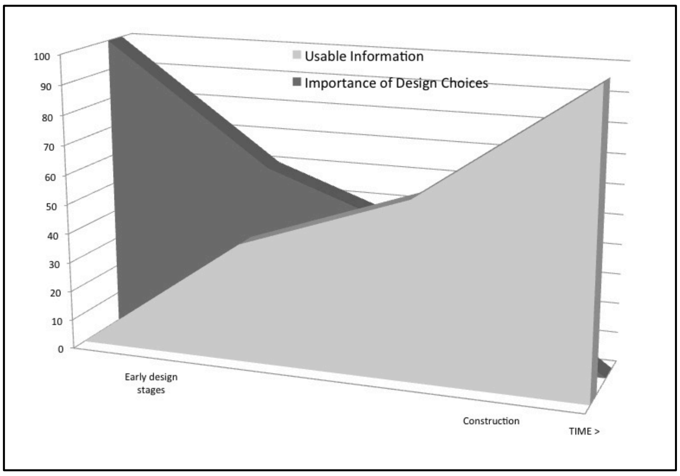

Figure 1 The paradox of architectural and urban design (Adolphe, 1995)

Therefore, the potential consequences of design support tools are highest in the early stages. They should rely on simplified but robust information on the design. The architectural design and urban planning processes are lacking for decision or evaluation support tools, especially during the critical configuration phases for the modeling process of cities. One of the main difficulties on building these tools rises with the simplification needed for modeling various urban elements and their relationships. In that sense, new research approaches have recently tried to fill this gap by improving validation on test cases, by integrating ranking between architectural variations in real practices (Adolphe, 1995; Fontenelle, 2012), or by a better integration of demand side management (Dubois, 2013). Therefore, it is necessary to develop assessment tools based on simplified models compatible with the level of information available during the various stages of the design process.

SYSTEMS OF INDICATORS FOR THE SUSTAINABLE DEVELOPMENT OF SETTLEMENTS

In this context, the most promising family of urban evaluation tools are based on systems of indicators able to integrate a wide variety of problems and the complexity of their interrelations in the space and the time (Adolphe, 2001; Josza, 2005 ; Adolphe, 2008; Adelle, 2009). The sets of urban indicators contribute to the building of systems in which development and environment are completely integrated. But currentlythese sets of indicators still remain very heterogeneous in terms of purposes as well as content.

But what is an indicator? Generally, indicators quantify information by aggregating different and multiple data. In short, “indicators simplify information that can help reveal complex phenomena”

(TERM, 2001). Compared to raw data used for example in the urban databases, single indicators are used to model the reality into decision support tools. These indicators would provide a representative picture of environmental conditions; being scientifically sound; being simple and easy to interpret; providing a basis for comparisons at various scales; integrating a target or threshold against which to compare environmental quality and performance (Alberti, 1999).

Therefore, how to build proper systems of indicators that exceed thematic, alphabetic, or just concatenated lists? How to interconnect indicators in systemic approaches characterized by strong interactions between subsystems?

Some characteristics of these systems are fundamental: 1) an indicator means nothing out of a system: there are strong links between indicators in a system; 2) a system means nothing elsewhere refering to fundamental issues. It is therefore necessary to build different systems for regulation compliance, decision support, simulation and evaluation; 3) a system means nothing without mixing physical, social, political scopes: each geographic scale or each actor may develop a specific system of indicators.

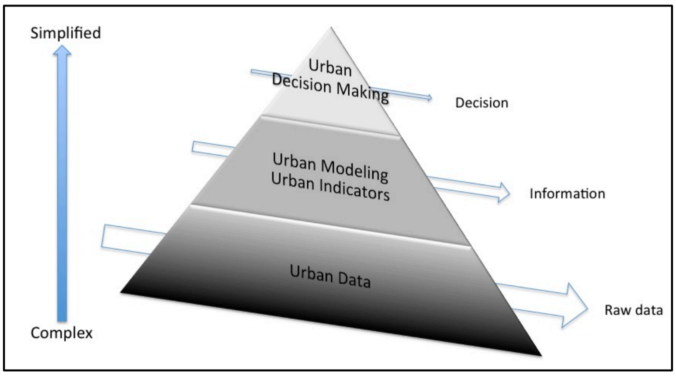

Figure 2 : Decision pyramid , from raw and complex data corresponding to real world, to simplified and abstract models useful in the decision process.

The first stage of building these tools is typically a structural stage. Some models have been developed to structure these systems: the PSR model "Pressure, State, Response" (RESPECT 2000) ; the DPSIR model : "Driving forces, Pressure, State, Impact, Response" (TERM, 2001); the DPSEER model : "Driving forces, Pressure, State, Exposure, Effect on Humans, Response" (Webster, 1996).

The second stage of constructing these indicators sets may rely on the aggregation of indicators into single index or composite indices. In the context of the sustainable development, one can say that this aggregation makes it possible: 1) simplifying, by reducing complexity, or simply reducing a great number of data into a smaller number of useful information for the evaluation; 2) quantifying, by modeling, simulating, and by building a comprehension of the phenomena and stakes; 3) communicating, by helping the decision makers to give their own opinion within the framework of a negotiation, an equitable exchange.

As a conclusion, the indicators are now popular and widely used in all organizations working on sustainable development. A consensus appears at least on the general characteristics of indicators. A good indicator needs to condense meaningful information into simplified, relevant, reliable, transparent, workable, synthetic, robust and correctly interpreted at the appropriate geographical scale. However, construction of current indicator systems suffers from serious methodological flaws.

The most important limitation of the current systems may be related to their construction method: these systems are based on a bottom-up approach, starting from the available data, without a global reflection about the goals to achieve. As a result, their gain to improve sustainability performance has been often limited (Alshuwaikhat, 2002; Seabroke, 2004).

The implementation of exhaustive top down approaches, starting from the fundamental concerns of the users of the system, to format and select the indicators could solve this problem. However, it should then iteratively combine with operational bottom-up approaches to reach a good compromise.

FROM SYSTEM OF URBAN INDICATORS TOWARDS DECISION SUPPORT TOOLS

To answer to this combined approach, we have moved off from this classical exercise of indicators concatenation, and to propose real decision support tools of the sustainable evaluation for urban projects, within an innovating morphologic and structural framework. This framework is based on the implementation, of multicriteria aggregation techniques. These tools allow to compare "the non-comparable", while implementing non-commensurable criteria or criteria which can get into conflict.

The main methods of multicriteria aggregation are primarily interested in alternatives or actions (Roy, 1985). They aim at putting forward the one or the better decisions to be taken, in comparison with the preferences of the decision-maker. These decision support tools are based therefore on a relative assessment: projects are compared to other ones in terms of sustainability performances. Some approaches are based on ELECTRE type methods, for ELimination and ChoicE Corresponding To Reality (Roy, 1993), and pairwise comparisons made without trying to bring the various criteria on the same scale value. They are able to manipulate complex concepts such as indifference, preference or veto thresholds to cope real-life decision context (Rousval, 2005; Fontenelle, 2012).

The multicriteria evaluation contributes to an exhaustive and synthetic census of information, while clarifying the results produced by the collections of indicators specific to each family of themes. The multicriteria evaluation is composed thus of two essential and indistinguishable aspects: the structuring model of information on the one hand and, the relative weighting of these criteria on the other (Adolphe, 2006).

The methods of partial aggregation are different from global aggregation ones mainly due to the three following aspects:

1) Data: evaluations of the indicators must be clear, probabilistic or fuzzy.

2) Operators of aggregation: the comparison of the evaluations of the criteria for each action can be performed by simple or complex fuzzy function (probabilistic or fuzzy evaluations). The over-ranking relationship between actions is established when a majority of criteria is better for an action than its competitor. The relations of indifference and incomparableness are also defined. The whole preference relations correspond to the criterion of over-ranking which constitutes the value of homogenization. Each preference relation represents the direction and the intensity of the preference between two actions.

3) Systems of preference: the decision makers define the weighting coefficients for the families of sustainability criteria.

This approach has been successfully used to evaluate the urban sustainability performance of urban designs at the district scale, in the SAGACITE Project (Adolphe, 2002). This project addresses the environmental influence of urban morphology at the neighbourhood scale. This work puts into perspective, objective indicators built from in situ measurements and environmental modelling, and subjective indicators related the perception of the users. The project is based on the simultaneous consideration of three concurrent areas: building, vegetation and transport. This resulted in the production of a decision support tool based on a Geographic Information System (GIS). This computing platform permits monitoring of existing urban projects (an “environmental dashboard”), comparison (intra or inter-urban) between sites, and scenario for urban spaces, taking into account environmental issues.

But the main limitations of this family of decision support tool are linked to the fact that they are based on relative assessment linked to partial two by two evaluations of actions. For most of the architectural and urban projects, practitioners are more obviously looking forward to compare their project with generic goals linked for example to its sustainability: this represents the shift between decision and evaluation support tools.

FROM DECISION TO EVALUATION SUPPORT TOOLS

"The evaluation process aims at quantifying and/or qualifying a system, thanks to all necessary information for building criteria allowing to attain the objectives concerning this system and pertinent in the framework of a wider activity but previously identified". Therefore the evaluation consists of "an assessment using criteria for achieving objectives or the degree of proximity of a project compared to a norm" (Abernot, 1996). Therefore, we distinguish the *decision*, for which we will compare several projects, based on a "relative" comparison (Roy, 1993) and the *evaluation* for which we will compare a project to goals or user's value systems, based on "absolute" comparison (Keeney, 1996).

The main motivations of these value focused approach are: 1) building a system of values as a reference for the evaluation; 2) knowing the reference system to understand the result of the evaluation; 3) explaining the system of values to justify the result of the evaluation; 4) communicating the system of values to build a consensus; 5) encouraging debate around the result of an evaluation; 6) monitoring the evolutions of the reference system for understanding the evolution of the evaluation.

In a first stage, we give privilege to the top-down approach, by defining the decision-makers' preoccupations for structuring the system of indicators, and by using a formal reconstruction system for the indicators selection.

When the object represents a major issue for the decision-maker concerning his position, it is a final objective, as opposed to the objective as a mean, which does not represent an end by itself for the decision-maker, but a means to reach a final objective. A strategic objective is a final objective that has the characteristic to be invariant during the time. A final objective can be decomposed; a means objective can be linked to various other ones (Fig.3-4). It is therefore possible to construct a structure (or hierarchy) of objectives for each decision-maker. To build the most exhaustive possible body of objectives, it is necessary to interview people representing each user group (Fig.5).

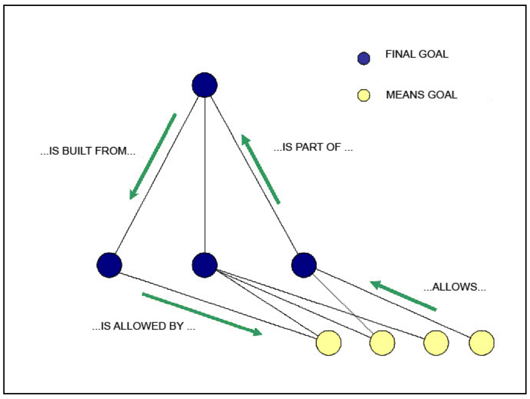

Figure 3 Relation between final and means objectives

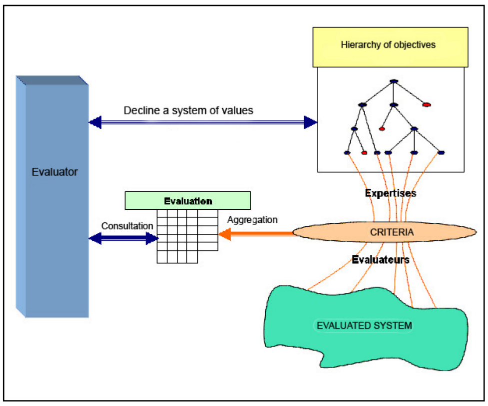

Figure 4 Application of the Value focused approach to our project (from Rousval 2005)

This value focused approach offers numerous advantages. It allows an interdisciplinary approach where the definition and the ranking of objectives structure the construction of the indicators system. It allows balancing objectives by propagating the weight in the hierarchy. Non-experts may use it to question and to structure the problems. At last it is easily applicable to wider contexts, such as sustainable development. The interviews are conduced in two stages. The first stage aims to define a first body of objectives. One lets the interviewee speak while asking non-directive questions. Taking some notes allows, then, to do a first census of objectives that appears along the interviewee speech. The second stage aims to explore the objectives that emerged from the interviews in the first phase. Thus, one can relate a means objective to an end objective while asking the question "Why this objective?". From a final objective, one can construct his superior hierarchy (bottom-up). To explore in depth the tree of the final objectives (top-down), one may ask "why this objective is important?" or "which facets of this objective are important?" (see Figure 5).

The last but not least advantage of the value focused approach is "the union" of several hierarchies, into a generic structure, while using a specific algebra (Keeney, 1992). One can thus structure the design of the system of common indicators for a population of decision-makers (Figure 6).

At last, we take into account the preferences of the decision-makers while using a multicriteria support method, the Electre-tri method (Yu, 2003). By using this method, it is proposed an ordinal evaluation of each objective.

- To master the environment
  - At the planetary scale
    - To preserve an environment in favor of human life
      - To limit the greenhouse effect
      - To limit the climatic change
      - To protect the ozone layer
    - To preserve the natural resources
      - To limit the extinction of natural types
      - To limit the extinction of natural environments
      - To limit the consumption of energy
    - To limit maritime pollution
    - To limit the production of persistent losses
  - At the local scale
    - Concerning natural environments
      - To limit impoverishment of landscapes
      - To limit the mineralization
    - Concerning human environments
      - Concerning public health
        - To limit the effects of the pollution of the air:
          - Of the peaks of pollution
          - Of mean pollution
          - To limit the effects of the accidents
        - To limit the effects of the noise on health
      - Concerning the life quality
        - To limit discomfort :
          - Due to noises
          - Due to smokes
          - Due to the odors
        - To improve the landscape
      - To improve cultural inheritage
      - To improve neighborhoods
      - To preserve the habitats from dust...

Figure 5 – Reduced and filtered hierarchy of objectives (from Rousval, 2005)

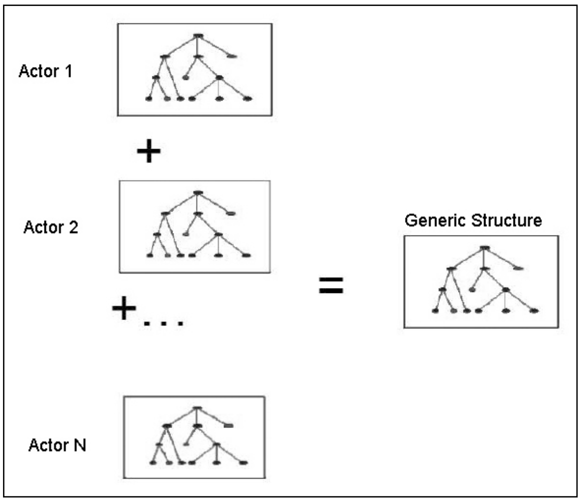

Figure 6: Union of deciders' hierarchies of goals into a generic structure (From Keeney, 1992).

This approach has been successfully used to evaluate the performance of urban sustainability of urban projects, in the PIE Project and to evaluation of sustainability of urban districts in developing countries (Adolphe, 2006). The "PIE" project aims to establish the specifications of a tool for the assessment of the environmental status of a geographical area selected in relation to the pressures (air, noise, water and soil pollution, impacts on space, on landscape, on fauna and flora, waste) enforced by the transport system. This tool for urban decision makers is based on sets of indicators structured by type of pollution. It enables a multi sectorial diagnosis from an aggregation of some (or all) of these indicators. These sets of indicators are based on two concurrent approaches: a top-down "back casting" approach based on concerns or objectives of decision-makers, and a bottom-up approach which starts from the operational constraints of the system. This tool uses multicriteria decision techniques allowing aggregation of basic indicators in sectorial indicators, and the construction of an operational approach for aggregating preferences of users of the system. This tool allows comparing the environmental impacts of different transport modes, technologies and policies.

The interests of this approach as well are numerous: the possible use of thresholds to consider the inaccuracy/uncertainty, the adequacy with the sorting approach, the comparison of the alternatives to a stable reference, the modularity, and finally, the incomparableness and no-compensation. The disadvantages are a weak readability and the lack of transparency. Possible applications of this method are the creation of a "global sustainability indicator", the support of activity-based "participative democracy" and the evaluation of "local and personalized follow-up".

CONCLUSION

Our work proposes a methodological framework for the decision and evaluation support of sustainable architectural and urban projects. The opportunities to use decision and evaluation support tools in the design or in the management process of architectural or urban projects are numerous. By simplifying a vast amount of information into a simple form, they make it much easier to read and understand complex reality and to help a new understanding of how urban systems work and how they interact with sustainable development at various scales (Alberti, 1999).

In a context where urban policymakers are, more than ever, challenged by the task of redirecting urban mutations into a more sustainable way, these new approaches are very challenging because they allow a good integration of the cultural or social dimensions of development. There is no point in building highly efficient cities, if they are not appropriate by their users, or if the spaces created do not meet their expectations or the representations of such places. “Sustainability, at the community level, is perceived as a holistic concept and not simply the sum of the environment, economy, society, and culture. The links among these components are established by the people and expressed in terms of people needs and aspirations” (Alberti, 1999).

We think that introducing these techniques into the design management process of architectural or urban projects brings new opportunities such as: 1) Avoiding to “bury” the practitioners in a proliferation of often conflicting and specialized information and constraints: help them keep up controlling the process that they are expected to master, so forth avoiding a divorce between design and production; 2) switching to a strategy of design “optimization” to a strategy of “reasonable compromise” between various constraints.

On the contrary, the limits and threads of these approaches are mostly linked to the context of sustainable urban development process itself. The decision is very complex and strongly context-related. Each new project is for example leading to a new set of indicators (Tanguay, 2010), and new user defines its own system of values (Kahn, 2006). These new tools are not designed for an automatic design but rather as a decision support in a specific governance context (Litman, 2011).

We have successfully integrated these various techniques to evaluate the performance of urban projects in developing countries in terms of sustainable development (Adolphe, 2006). The next step is to interbreed various themes simultaneously, such as building and transportation (Santos, 2013). Another development envisioned is to focus on the robustness of these systems, by testing the resilience of the threshold measurements. Even though this assessment presents difficult tasks, it is an unavoidable step in order to translate that new knowledge into effective policies.

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Eco building schools in remote places | Case study: Cunene, Angola

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ABSTRACT

The need for more environmentally responsible practices is unquestionable in the scientific community and the construction is responsible for a large part of energy consumption and consequently for the environmental degradation. It is the architecture`s duty to modify this panorama, intervening in a way that is conscious and alert, both environmentally and socially, following the development of societies and their emerging needs. This paper aims to develop an intervention strategy, in an underdeveloped region, more specifically, in Cunene in southern Angola, projecting a model of pilot schools, low cost and with low incorporated energy costs, duly adapted to the climate specificities. The Cunene is an Angolan region which obtained most of their livelihood over time with the livestock. However, like so many other places, it lacks of educational structures that enable its development and that provide higher levels of learning to the community. The project includes the use of local ecological materials such as earth and bamboo. Enabling people to participate in the entire construction process, by moving knowledge to enable the development of the local economy, particularly in the production of adobes. Therefore, the community and the man have an active key role throughout the project. The land is withdrawn from a nearby project site, by appeal to human labor instead of the machine. In the case of bamboo, it is anticipated planting a species that best suits the local climate and construction. The whole proposal is designed so as to respect the three basic pillars of sustainability: economy, environment and society. Allowing these locations to progressively develop and so that social justice can be found.

INTRODUCTION

The present case study is located in the Cunene region, in the southern border of Angola. This choice is directly related to the evident lack of educational infrastructures in the region, as well as the high number of children outside of the school system and with the conviction that it is fundamental to invest in education in order to develop populations that reside in remote locations. It is essential to the decrease of illiteracy among its people and vital to the local and regional development.

According to various studies, most of the poor population on earth lives in rural settings. In this sense, the education of the population becomes extremely important and the community must participate in this process, becoming the foundation of the local development, while promotion civic and educational developments.

GENERAL FRAMEWORK OF THE ANGOLAN TERRITORY

Angola is located on the west coast of Southern Africa, bordered by the Republic of Congo to the north, to the east by the Democratic Republic of Congo and Zambia and Namibia to the south, making a land border of 4690 km. To the west it is bordered by the Atlantic Ocean shipping line corresponding to 1650 km long. (1)

The Angolan territory corresponds to a total area of 1,246,700 km2, dividing them into 18 provinces, which in its turn are divided into 163 municipalities subdivided into communes.

The official language is Portuguese, spoken mainly in the cities. However there is a panoply of other languages used by its inhabitants, being distributed by well-defined geographical areas. The better-known languages are Umbundo, Quimbundo and Quicongo.

According to the last census in Angola, which dates from 1992, it was estimated at 10.31 million inhabitants, mostly from rural areas - about 6.159 million inhabitants - which corresponds to 59.7 % of the total population.

The oscillations of the population have always been a constant in Angola, especially during periods of civil war, that caused constant displacement of the population, migrating to cities or emigrating to neighbouring countries.

Currently there is a steady exodus of younger people from rural to urban areas, in search of better quality of life, particularly due to the growing job search. So it becomes even more evident the need for emergent interventions in remote areas, unprotected and devoid of infrastructure resources, as well as becoming increasingly depopulated. This migratory population exacerbates already serious problems of uncontrolled growth in the suburbs, where extreme poverty is evident, showing serious housing, health, employment and illiteracy issues.

Several studies show that the majority of the African population is young with low education levels, a result of various factors - including the Civil War action - as well as economic and social factors, on which the action of the state is not sufficient to meet the current needs.

The climate in Angola is divided, generally, into two seasons: wet and hot summer, corresponding to the months from October to April and winter (known as *cacimbo),* corresponding to the months of May to September, dry with lower temperatures.

The morphology of the Angolan territory develops about 60% in highlands, which naturally influences regional climates. Cumulatively, we can see the influence of the cold Benguela current and the coastal breezes. All these factors are responsible for small local variations in climate, although the average annual temperature is high throughout the country.

Education in Angola

Focusing this document in our area of research: primary schools in remote environments, more specifically in the Cunene region, we realize the organizational logic of education in Angola.

The Angolan education system is divided into three levels: primary, secondary and tertiary. However, in order to reduce the deep levels of illiteracy and lack of education of a large population, noted mainly in rural areas, the subsystem of adult education emerged.

According to Trade and News Magazine, *"22% of Angolan children of school age are out of school in urban areas. In rural areas, the estimate is 44%. Failure at school measured by the sum of the rates of repetition and dropout is extremely high, reaching figures of around 50% for 1st and 2nd grades. 42 % for 3rd level of Regular Education. Regarding the dropout rates, the statistics presented indicate that 12.5% of children drop out of school in urban areas and 25 % in rural areas (...) "* (3)

It is noteworthy that the few schools operating in remote areas, hold serious construction problems, not being provided with the basic conditions for an adequate level of education. Many of these classrooms are constructed using solutions of "wattle and daub", using only local materials easy to obtain. However, the lacks of constructive knowledge, either endogenous or technical, have limited the quality and number of suitable classrooms.

Serious socio-economic problems, seen in this country, such as extreme poverty and social inequality are due largely to an inadequate education system, the result of prolonged civil war, and also due to the lack of physical structures and educational resources that enable a way of integrating active citizens in local and regional growth.

Figure 1 Classrooms at the Catholic mission of Okaunatoni, Cunene, in May 2013.

The lack of adequate primary schools subsequently condemn the formative and educational capacity of its citizens and inherently stall the growth of the country.

In remote or rural settings, this reality accentuates migration to the big cities, forcing this population to survive in the suburbs, deprived of employment opportunities or minimum health conditions, whereas if provided with adequate training in their unique environments they could secure better livelihoods and resiliency within their communities, thus enabling local development of consistent and sustainable manner as an alternative to migration to cities.

IMPLANTATION OF THE PILOT PROJECT

The proposed project intends to develop as a model for regions with the same geomorphological, social and human characteristics, duly adapted to the constructive specificities of each place.

It is located in the Catholic Mission of Okaunatoni in Cunene, southern Angola. And due to its difficult access, where most of the roads that connect to the mission are made of sand and because it is situated about 30 kilometers from the nearest locality - Xangongo, the resources and labor become scarce and difficult to obtain; there is an absence of construction companies operating in the local, or the ones that eventually mobilize to these places present honorary fees incompatible with the most disadvantaged populations. These factors, in addition to those that will be mentioned later in this article, reinforce the need for a project made by people, using locally available materials and easy construction.

Figure 2 Location of project implantation and current location of the classrooms at the Catholic mission of Okaunatoni, Cunene. No scale.

The considerations / limitations with the surroundings of the project, with local populations or climate conditions are some of the criteria to be taken into account in formal conceptualization of the design solution. We intend to develop a solution that is functional, educational and acts as an empowering tool for a constructive change paradigm based on locally available materials.

We intend to use locally extracted materials, with local labor, and give men and women leading roles throughout the construction process, contributing to a more active and participatory architecture. Therefore, the communities will be taught new valances that will enable them, in the future, be able to build their own houses as well as doing its maintenance, without being limited to the will of the government, which little supports these more remote communities.

The architecture has a key role in developing a methodology grounded in research and construction methods validated laboratorially, which will optimize techniques and local resources to build sustainable buildings at a low cost, such as the present study. The construction of pilot schools, with subsequent measurement and validation will ensure access, quality and educational equity to local populations.

The architect gains a role on this project that becomes more than an agent of change, beyond the designer role, contributing to the socio-educational integration of people and hence the sustainability of the most remote locations.

The aim of this work was to define innovative principles and essentially structural design recommendations for building cost-effective pilot schools for the regions of sub-Saharan Africa, anchored in bioclimatic principles and constructive, economic and environmental sustainability, addressing the specific conditions of each target region.

Main Planing Principles | Case Study

In this proposal we develop a series of bioclimatic principles that claim, through a rational use of natural resources, to better integrate the school building on site as well as reduce the costs of future maintenance of the same, ensuring comfortable and properly balanced environments, adapting available to local and improving their technical reality resources, so enabling them to prolong the life of the buildings.

Immediately we will consider the actual shape of the building, including its design. The solar orientation, natural ventilation and the correct choice of materials are essential principles for an integrated and properly adapted architecture.

The program of the proposed building is relatively simple, consisting only of two blocks of classrooms and a separate block with their sanitary facilities and a covered outdoor living space. Trees are to be planted in the patio, so as to ensure greater shading of buildings and, on the other hand, to ensure a slight cooling of the temperature. The shape of it will also be a simple consequence of the program itself and the choice made on the construction of the building: local materials and local labor.

The buildings will be deployed on a slightly raised platform floor level, thus protecting them from the risk of flooding - very common in the region - and secondly, to avoid the excessive wear and degradation caused by the action of water on the foundations and walls of adobe. This way the foundation and plateau will be built, if possible using stone, and in its absence, using repellent mortar in order to consolidate and stabilize, if exceptional circumstances of flooding may occur.

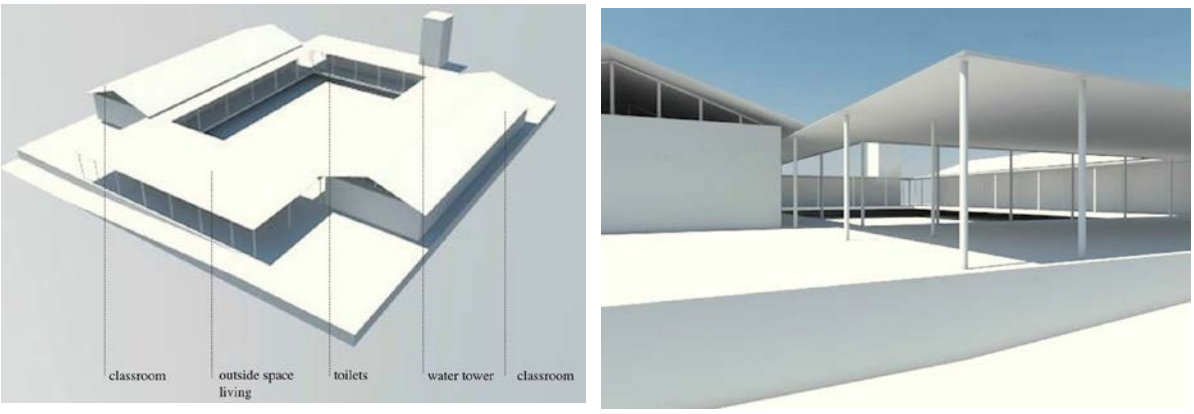
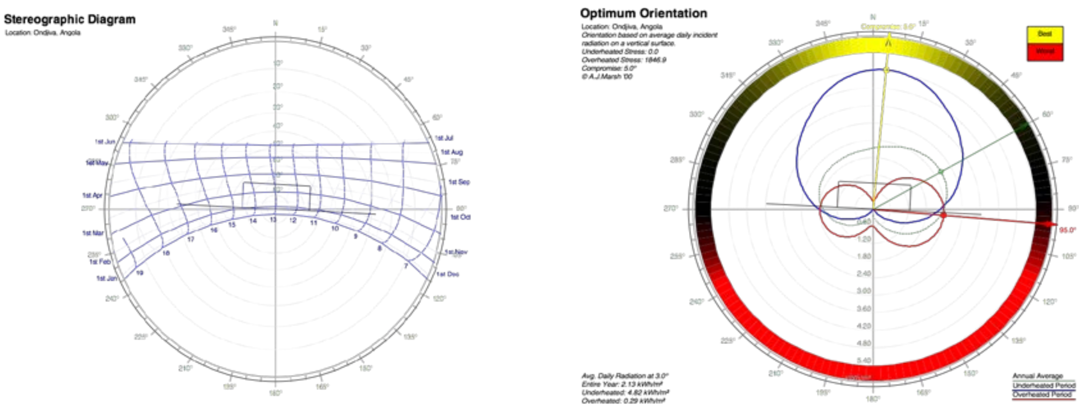


Figure 3 Organizational schemes of pilot school, Cunene, Angola.

Figure 4 - Angola' s map - Ondjiva (17°01'40.4"S 15°03'06.6"E)

The walls in raw ground work as support to a structure of bamboo which will anchor the coverage of the building, coated by sheet metal. Adequate ventilation of the building will be ensured by gables, releasing the wall of the casing, thus contributing to the cooling of indoor spaces and to reduce moisture levels, asserting the air quality and comfort.

The school will be located under the guidance recommended in Figure 5. These studies as well as showing the solar path in Ondjiva, during different periods of the year, show us which is the optimized solar orientation for this region.



(a) (b)

Figure 5 - (a) "stereographic diagram for Ondjiva, showing the solar path in the various periods of the year" (b) optimized solar orientation for Ondjiva (5 º C) " (4)

The special configuration responds to the better orientation of classrooms, oriented in east / west direction, with the biggest facades turning to north and south, getting the best sun protection as well as lighting. Similarly, the toilets are placed intentionally so that setting the assembly to solar radiation throughout the day and year, as it may function as a natural sterilizing action of such areas that require greater care and control of fungi. It was also ensured a covered patio to the east, as well as outdoor galleries to ensure sheltering from rain and solar radiation to users throughout the year.

As mentioned earlier, this study serve as a prototype intended to be "replicated" in other places, with human, social and economically similar characteristics. Most importantly, we must bear in mind that "new projects" have to meet with the real needs of populations and adapt to the context in which they are entered, including solar orientation, the wind regimen, the labor and locally available materials. Therefore, it will be enabling a better adaptation of the shape / design of the place where the constraints will be installed.

Applied Materials

The earth as a building material has been the subject of some reluctance in the target countries of study, as its use is associated with a stigma of poverty and insecurity that people want to avoid. However, it is essential to realize that this preconceived idea is anything but reasonable and realistic. Initiatives to improve these communities should meet their needs, and earth is a material that fully meets the needs of the community, with economic and environmental advantages and ease of application with hand-local labour benefiting from this.

It is a local, natural, recyclable, non-polluting and foremost reusable material. A building on earth can simply stop being and the material returns to its origin being returned to nature without intervention or expenditure of energy or human action, characterizing the earth as a material with a closed cycle. Although besides these qualities, many other criteria lead us to choose the land to the detriment of other materials.

In hot climates, such as Cunene, issues relating to thermal inertia of the materials are very relevant and should be taken into account when designing a school building. The earth has the ability to regulate and smooth the external temperature fluctuations, maintaining the coolest spaces in warmer periods and in turn, maintaining milder temperatures when the weather cools, particularly during the daytime and night time periods.

The soils in Cunene region are very sandy and as such they require a binder material that unifies the mixture and makes it cohesive, capable of being used for construction. Consequently the addition of other materials in order to correct this situation is required. It is expected to be mixed lime or cement, whichever is easier and convenient to purchase on site.

Despite the obvious durability that buildings have on earth, simply because there buildings constructed with use of this material continue to leave your testimony in our landscapes, studies have been shown that the addition of other stabilizing components prolong their good conservation and avoiding construction issues, their natural erosion, particularly that caused by water.

Figure 6 "Stretches of rammed earth walls exposed for 20 years to atmospheric agents: (a) wall, stabilized with 5% lime earth; (b) on the ground without wall stabilization (mixed soil); (c) Wall ashore without stabilization;" (5)

The study corresponding to Figure 6, aims to demonstrate that the addition of stabilizing elements, such as lime, protects the walls exposed to weathering, from the erosion that is naturally subject. Consequently the stabilizer prolongs the good condition of the building, providing more stiffness and durability.

Since the buildings on earth are already being disseminated in much of the territory and becoming a current practice in these environments, it is intended that the community re-acquires the right knowledge, and adjusts its implementation and that consequently there is a constructive improvement of these practices. It is not intended that these techniques are vernacular revival, but rather, to adapt to new realities to constructive development. For all that, and the current resistance observed in these locations due to the onshore construction, we propose the application of plasters in order to address the weaknesses of the material.

Traditionally, in Angola earth constructions are already built with thatched roofs, but this material presents some weaknesses at the expense of others, especially in their natural susceptibility to the possibilities of fires. Cumulatively, the use of the stem for several years, has led to its gradual disappearance, not being available in construction sites, implying major shifts to its acquisition. Still contributing to the cause of the abandonment of this material, the current population has new rhythms of life that does not allow them to do the right and necessary maintenance to keep the stem is in good condition.

In contrast to stem use, we propose the use of sheet metal. This material allows for a lighter support structure, since the material itself has little weight. Its displacement and application is relatively simple and does not require maintenance during the lifetime of the building.

Even though it is not a local material and considered sustainable in origin nor incorporation associated with energy, it is affordable, durable, lightweight, flame retardant, low cost and easy to transport. The application of the coating material enables to lighten the supporting structure and by their individual dimensions of each sheet cut together, the weak points of rain and wind action.

To the support structure it will use the coverage at the expense of the bamboo wood, commonly used in the region. The bamboo has a relatively rapid growth compared to other materials, within 2-3 years it can be extracted from the site and is mature enough to be used in construction. We intend to proceed with the planting of a species in a nearby location that best suits the local weather conditions and has the height, diameter and thickness suitable to be used in the construction of the building.

Unlike wood, which requires a much longer process of growth and still requires the use of machinery to cut and modelling, thus incorporating more energy in its transformation and the consequent need for more expensive and complex equipment, bamboo uses are very simple, economical and without the need of power tools, verifying a minor impact on the environment.

After the extraction of the material - and this is in the place where it will be used - there is a mechanism of preservation, which in addition can prevent rapid degradation, since the material has little resistance to micro-organisms and insects, it will increase its durability. This process can be done in two ways: by chemical or non-chemical methods. In this proposal we will use a non-chemical process where the bamboo is stored in tanks of water and could thus decrease its starch content, which will consequently make the plant more resistant to biological organisms and increase its durability. This technique of leaching of bamboo is an ancient method and used for several years in different communities to protect the material from the draining action of organisms. However, its variation is directly dependent on the durability of the species concerned and it might turn this treatment insufficient and it is necessary to add a chemical components into the water so as to make tougher materials.

One of the objectives pursued, when the choice of materials is bamboo, is to introduce new materials, with easy extraction and handling, responsive to the needs of these communities. Since there is still a profound lack of knowledge about these techniques, the population tends to reject it, even if unconsciously, so you will need to "democratize" and promote its use throughout a process of adaptation to the material, instructing the local population so it will benefit from constructive greatness of it, as well as the possibility of its using in other capacities - not only construction, but also with applications in woodworking and carpentry, with the construction of furniture.

There are already some examples of buildings in remote means, which involve the use of bamboo to make the structure of your toppings. Among them, we highlight the Handmade School in Bangladesh by

the architect Anna Herringer and the Habit Initiative Cabo Delgado in Mozambique, by the architect Roswag Ziegert. (figure 7)

(a) Handmade School | Bangladesh (b) Habit Initiative | Mozambique

Figure 7 Bamboo structure construction by the local population

CONCLUSION

Local interventions of apparently little scale have global repercussions. It is vital that we intervene locally so that the long term scenario is different, dignifying the most disadvantaged communities.

However it is essential that the scientific community realizes that behind the choice of certain materials are rooted local prejudices that must be understood and taken down or assimilated and managed for an innovative solution that can be attractive and harmless on local traditions. The blind imposition of new solutions seen as superior risks the non-assimilation and not being fully understood by the target population. All communities have their patterns and desires that must be respected and reconciled in the intervention. Concessions on certain points of intervention should be taken into consideration, as the scientific community should cooperate and not solely teach, share knowledge and not just impose.

Photographic examples of schools considered "bio" and "eco" in remote environments advertised as examples for the scientific community are constant in failure in their places of deployment, for they were not assimilated by the population, resulting in innocuous buildings without result in pilot examples for the region. Certain orthodox and rigid solutions without added local inputs resulted in unique and beautiful examples, but not replicated, either by training difficulties of the population, or simply by their lack of identification, assimilation and understanding of forms of use, habits and customs.

It is our understanding that a sustainable conceptual solution for the measurement and scientific validations should be downstream of understanding anthropological and socio-cultural assimilation, and incorporate local religious architecture in the draft. This should just be a reflection of local and scientific assignments and reconciliations.

Acting locally avoids successive massive displacement of populations to cities and consequently decreases the informal, illegal and uncontrolled development in the outskirts of cities. Remote, inhospitable and prone to decay stands can gain new lives with this kind of interventions, that are beyond architectural, becoming social and economic transformations.

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Session PD: Thermal comfort

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Trust - Knowledge Consortium of Gujarat

Integrating User Awareness and Behavior into Building and Product Design for India: Survey in Eight Giant Cities in India

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ABSTRACT: Is India on a sustainable road or not? Between April 2012 and January 2014 the authors have conducted a quantitative paper and online based user survey on energy awareness and attitudes in Mumbai, Bangalore, Chennai, Delhi, Pune, Hyderabad, Ahmedabad and Kolkata. The survey was part of the project "Clime Related Energy Efficient Design - Product Solution (CREED-PS)" first funded under the aegis of Germany India Year 2011-2012 "Germany and India: Infinite Opportunities" with a focus on "City Spaces" and then as part of the project "DWIH Excellence on Tour. 2013-2014." More than 2000 visitors were interviewed during the events about their individual energy consumption, their knowledge of selected energy issues and energy efficient building design and their sustainability attitudes. The majority of the visitors are part of the academic middle class group in India's Megacities, as a limited group of India's society. One of the main results are that living in energy efficient residences is very important for most of the respondents, although two third don't know exactly the energy consumption of their household. Yet, most of the respondents are willing to spend more money in energy efficient and energy saving building devices and household equipment. Summing up one can say that the interviewed middle class group (Shukla, 2005, Mawdsley, 2004) is on the sustainable road, although we have identified several inexplicable contradiction in knowledge and awareness as topics for further research work that are relevant for building and product design. This paper illustrates on the one hand the use of survey as part of an integrated design process and suggests on the other hand collaborative approaches to educating architecture and design students about sustainability in building and product design.

Keywords: India, Energy consumption, Energy saving, Energy efficient building design, Sustainability, Standards of housing

INTRODUCTION

Today India is an emerging country with a 1.3 billion population (MHA, 2011) and a rapidly growing economy. The census 2011 estimated 168 million households in rural areas and 79 million households in urban areas. Most of Indian families and individuals still live in traditional rural houses or in buildings that are older thirty years. Yet, the economic boom since 2001, a growing middle class in Indian cities and the migration of people from rural areas to urban areas has accelerated a tremendous construction and investment boom in rapid sprawling metropolitan areas. According to the report of Global construction perspective Ltd. (2011) between 2013 and 2020 India will become, behind China and US, the third biggest construction market in the word with an annual growth rate of 8 %. It is more than evident that India with its high demand of construction material and energy consumption moves straight to a critical resource shortage and carbon emission collapse, if the government and the society do not counteract with sustainable strategies and action plans for energy efficient building design and energy saving technologies. With about 39 % of the total national energy consumption the construction and building area is the major energy consumer (de la Rue du Can, 2009).

In many discussions with Indian architects, scientists, energy experts and organization, e.g. the Bureau of Energy Efficiency (BEE) and the India Green Building Council (IGBC), it was mentioned repeatedly that the awareness and knowledge of stakeholders, investors and users plays a central role in the change process to more sustainability.

In general only few studies and publications about the mindset of the Indians on energy concerns are available. Alam, Sathaye and Barnes (1998) reported in an older survey of household energy use in the city of Hyderabad. The survey revealed the fuel transition from biomass-based fuels to modern fossil fuels and electricity in cities. Reddy (2004) using the data from the National Sample Survey (1983-2000), analyzed the dynamics of energy end-use in household sector in India. The paper reported that large variations in energy use exist across different sections of households urban/rural, low/high income groups, etc.

In 2011 the Mercom Capital Group (2011) conducted a survey on renewable energy awareness in the area around the cities of Bangalore and Mysore in Karnataka State. The limited survey based on 101 respondents of the rural area, 204 respondents of residential and 204 of commercial/industry. Overall findings of the survey were that a "general lack of education and understanding about renewable energy, though the people surveyed were very enthusiastic about renewable energy concepts". Only 39 % of the rural respondents have heard the term „renewable energy" or „clean energy", in difference to 61 % of the residential/commercial/ industry respondents. About 32 % of residential and commercial/industry respondents answered that they have installed solar water heater, 6 % have installed solar panels, 1 % used wind turbines, 2 % biomass and about 60 % had no application of renewable energy installed (Mercom Capital Group, 2011). Likewise interestingly is that 46 % of all respondents don´t plan to install any type of renewable energy in the near future and 62 % were not aware (rural 80 %) of any government subsidies for renewable energy.

In another national survey on "Climate change in the Indian mind" by the Yale University, GlobeScan Incorporated, and C-Voter 4,031 Indian adults were interviewed, using a combined urban (75 %) and rural (25 %) sample. This "study was designed to investigate the current state of public climate change awareness, beliefs, attitudes, policy support, and behaviors, as well as public observations of changes in local weather and climate patterns and self-reported vulnerability to extreme weather events." (Leiserowitz, 2012). The key findings concerning climate and energy policies were: "41 % of respondents said the government of India should be doing more to address global warming; 54 % said that India should be making a large or moderate-scale effort to reduce global warming, even if it has large or moderate economic costs; 38 % said that India should reduce its own emissions of the gases that cause global warming immediately, without waiting for other countries; 70 % favored a national program to teach Indians about global warming; 67 % favored a national effort to help local communities build check dams to increase local water supplies; a majority of respondents favored a variety of policies to waste less fuel, water, and energy, even if this increased costs; 53 % said that protecting the environment is more important, even if it reduces economic growth, while 28 % said that economic growth is more important, even if it leads to environmental problems" (Leiserowitz, 2012).

AIM AND OBJECTIVES AND HYPOTHESES

The survey aims to assess energy efficiency awareness of the users in India and potential for integrating the same in building and product design.

Overall objectives

The survey followed some overall objectives related to the described target group:

1. Identification of knowledge, attitudes, awareness and behavior on energy issues to develop new concepts for energy efficient buildings in India.
2. Identification of different climate-related and city-related life-styles, housing, and amenities demands.

3. Identification of awareness/needs/methods/approaches to improve the efficient building design for investors and the energy saving behavior of urban dwellers.
4. Involving businesses and corporate social responsibility for promotion of energy efficiency and sustainable consumption.
5. Identification of energy efficiency related topics for information and education programs.

Research hypothesis

The survey is based on the following hypothesis that should be proofed:

H1: Higher educated people of the new middle class in urban areas have a clearer awareness and higher needs on energy-efficient lifestyle than lower educated people.
H2: The higher the income of people the lower the awareness of energy issues.
H3: Females are better informed on energy saving and efficiency than males.
H4: Younger dwellers are better informed on energy saving and efficiency than older dwellers.
H5: People with high individual energy consumption are willing to spend more money for energy saving activities.
H6: A good residential place has a higher priority than the distance to the working place.

METHODOLOGY

The survey was conducted in Mumbai (April 2012), Bangalore (June 2012), Chennai (August 2012), Delhi (October 2012), Pune (January 2013), Hyderabad (April/May 2013), Ahmedabad (November 2013) and Kolkata (March 2014) during the events "Germany and India: Infinite Opportunities" and "DWIH Excellence on Tour. 2013-2014." The majority of the visitors are part of the academic middle class group in India´s Megacities, as a limited group of India's society. More than 2000 paper-based questionnaires (250 for each location) were disseminated and collected. All filled out paper-based questionnaires were captured automatically with a scanner. The statistical evaluation of the questionnaires was conducted separately for each city and altogether for all cities. In total more than 2000 visitors were interviewed.

The paper and online-based (CREED) questionnaire in English language was created with the web-based software (EvaSys)˙ Altogether the questionnaire was divided in 6 sections: (1) personal details, (2) mobility, (3) environment, (4) aspects for choosing the apartment/house; (5) environmental aspects, (6) general aspects. Questions were created in different formats (scale, single- or multiple-choice, and open).

In all automatically generated pdf-reports with EvaSys the case numbers were indicated for each question. Single-choice-questions and multiple-choice-questions were generated as a bar graph. Scale questions were generated as a histogram with average values, median values, and standard deviation. Additional the scale questions were diagrammed as a profile graph. Open questions were automatically identified and copied in the report as a picture-file. In the online-version open questions were recorded directly. For further statistical analyses the raw data were converted to an SPSS-file. The analyses were done with the statistical package SPSS version 20. In order to find out pattern in the data with a very strong correlation (r-value) and a very high significance (p-value) we conducted cross tabulation of age, sex, income, and occupation for all variables (items) in the questionnaire.

SURVEY RESULTS

General and Personal Data of the Respondents

More than one third (38.8 %) of the respondents live in a typical middle-class household with 4 persons. Nearly half of all respondents (45.3 %) were aged between 20 and 29 years. Only a small number of respondents (6.3 resp. 3.3 %) were older than 50 years. The majority of the respondents (77.7 %) were males. 65.5 % of the sample has a bachelor or master degree. This high %age depicts a strong focus on respondents with an academic background. The monthly income of the respondents is likewise nearly equally distributed. Probably the income group below 20.000 Rs. (37.7 %) consists predominantly of students, freelancer or housewives. 27.7 % belong to the lower middle class has a monthly household income between 20.000 and 40.000 Rs.. 34.6 % belong to the upper middle class has an income above 40.000 Rs. (Meyer and Birdall, 2011).

Priorities of Housing Standards

In the first part of the survey the respondents were asked about the most important factors for choosing a new residence as an indicator of life-style, social priorities and sustainability awareness. Fourteen (14) social related, building related, life-style related and energy related questions were provided. The highest priority to choose a residence was a high performance of the location (73 %) followed by security of the location (70 %).

Figure 1 depicts the confirmation resp. the importance of the fourteen (14) investigated factors on living standards in the eight included Indian cities. The respondents could answer between "very important" and "unimportant".

Q: To choose a residential for me is very important ... (% of respondents)

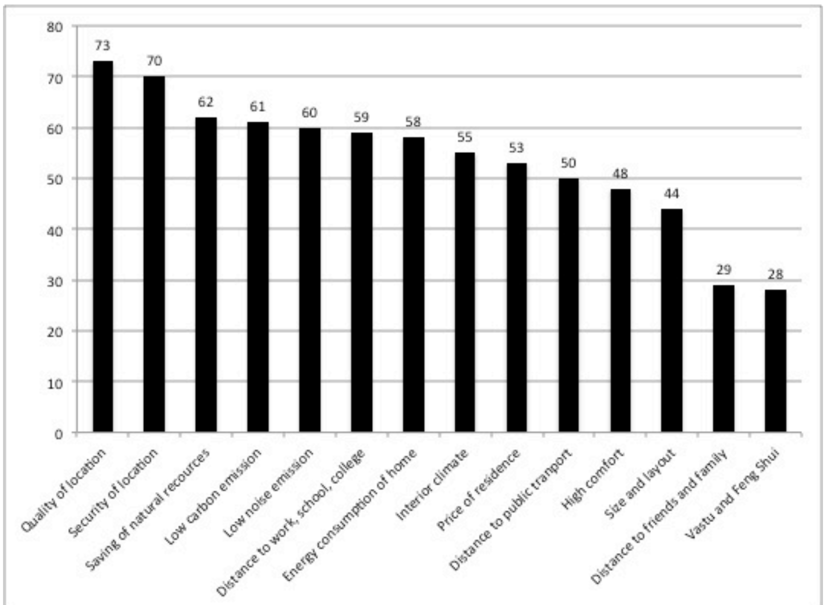


Figure 1 Overview of living standard priorities

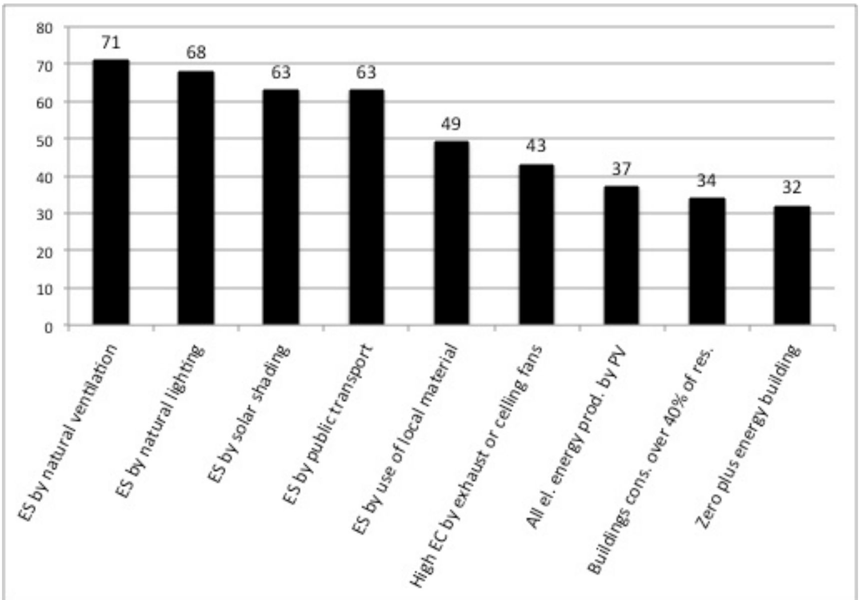
72.5 % of respondents consider a high priority of the location (district/quarter/street) for the apartment or house. This criterion of living standard has been the highest value of confirmation with an average value of 1.4 and a median of 1.0 with a deviation of 0.8. Because, this criterion implies a lot of sub-criterions like social and ethnic structure, population density, security, infrastructure (water and electricity supply, sanitation, garbage collection etc.), shopping opportunities, access to public transport, proximity to schools and kindergarten, cultural amenities, medical care and hospitals etc. The lowest confirmation of living standards of the respondents has "vastu" and "feng shui" with 27.9 %. A nearly equal share of 31.4 % find that unimportant. The age group above 60 years gives more importance to "vastu" and "feng shui" compared to other age group under consideration. The income group of 20,000 – 40000 Rs. places higher importance to "vastu" and "feng shui" in comparison to lower and higher income groups.

Other factors like saving of natural resources, low carbon emission, low noise emission, distance to work etc. and further investigated factors lays close behind the two top priorities. Amount of energy consumption, interior climate, price of residence, distance to public transport, home size and layout are less important factors to the respondents.

Environmental Knowledge and Attitudes

In the second part of the survey the knowledge and attitudes on building and product design issues should be identified. Nine (9) questions of use of material and electrical home equipment were provided.

The following Figure 2 depicts the knowledge and attitudes of the respondents on the nine energy related fields. The respondents could answer between “very familiar with …” and “not familiar with …” (% of respondents).



Legend: ES = Energy Saving; EC = Energy Consumption; PV = Photovoltaic´s

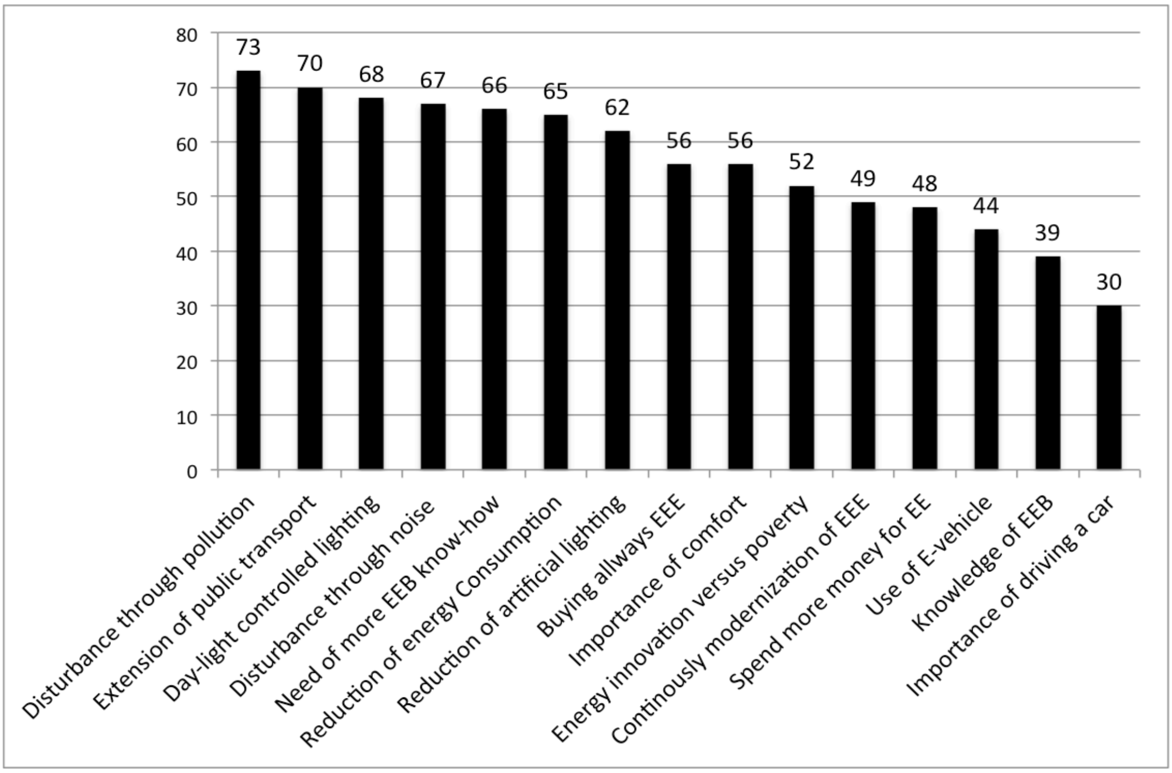
Figure 2 Overview of environmental knowledge and attitudes

71.1 % of respondents were very familiar with the fact that natural ventilation contributes to energy saving. A similar high confirmation of energy saving measure we have seen by the items of natural lighting (68 %), solar shading (63 %), and public transport (62 %). Saving energy by using local material (49 %) was not aware by nearly half of the respondents. Only 34.2 % of respondents were very familiar with the fact that buildings consume more than 40 % of all resources; 18.6 % were not familiar with this fact. 31.5 % of respondents were very familiar with the fact that buildings can produce more energy than they consume; 23 % were no familiar with this fact. As well only 32 % of the respondents knew that Zero Plus Energy Buildings could produce more energy as they consume. All in all these results shows a widely superficial knowledge of the respondents in the field of energy efficient building designs since the users are well aware of the basic energy saving measures like natural ventilation and lighting but they are not aware of the state of the art of energy savings strategies like zero or plus energy buildings.

General Attitudes of Housing

In the third part of the survey the general attitudes of housing related to building and product design was investigated. Fifteen (15) questions related to energy consumption attitudes were provided. The extreme poles of this question battery were on one hand side disturbance through pollution (73 % agree strongly) and on the other hand side importance of driving a car (only 30 % agree strongly).

Figure 3 depicts the general attitudes of housing in the fifteen items. The respondents could answer between “I agree strongly with” … and “I disagree strongly with …” (% of respondents) on Likert scale.



Legend: EEB = Energy Efficient Building; EEE = Energy Efficient Equipment

Figure 3 General attitudes of housing

The most important issue of the respondents is the air pollution. 73 % of respondents assert that air pollution is a very disturbing issue for them; for 91 % it is disturbing and very disturbing. The second important opinion focused on the extension of public transport (70 % agree strongly). In the following ranked items we found in general a linear decline of agreements. Yet, concerning the consuming attitude of the respondents one can consider a significant difference between the age groups. In general the older the respondents the more they have the attitude to buy energy efficient building equipment or amenities. In general one can assess a trend the higher income the higher are the tendency to buy always energy efficient equipment.

Interestingly, the alternative question that in the long term perspective innovation in energy saving is more important than fighting against poverty was strongly agreed by 52.3% of the respondents. This phenomenon is probably strong related with the particular structure, occupation, income, education, attitudes and behavior of the Indian middle-class. “It is by reckoning the most polymorphous middle class in the world.” (Beteille, 2001).

Concerning the knowledge about energy efficient buildings is was intended to measure the level and intensity of knowledge and information of energy efficient buildings. These values inform about the relevance of the topic for the respondents and for further information and promotion campaigns. 39 % of respondents assert strongly that their knowledge about energy efficient buildings is good, 70.3 % answer “I agree“ resp. “I strongly agree“. Between the age groups one can consider a tendency of higher knowledge in the age group 20 to 29 years and in the age group above 60 years.

48 % of respondents assert that they would spend more money for an energy efficient home, 79 % agree and strongly agree. The age group of 50 to 59 years has higher percentage of people who agree strongly for energy efficient homes. The group with higher income > 40000 Rs. place higher importance to energy efficient homes.

A deeper look into the age groups shows, that the high confirmation of the group above 60 years is very conspicuous and the increase of confirmation in the younger groups. The highest rejection one can see interestingly in the group below 19 years. Concerning the income groups there are no significant differences in confirmation or rejection. Merely in the income group 20.000 to 40.000 Rs. one can assess a higher value of rejection. Interestingly, in this question the “neither nor“ group is especially wide. All in all one can suppose a difference between to own a car as a status symbol and to drive a car actively under the current traffic circumstances.

CONCLUSION

In this article a selection of assessments of attitudes and awareness of energy consumption is shown and discussed. The hypothesis H1, H2, H3, H4 cannot be confirmed. In most of the measurements all respondents with a tertiary education have a clear awareness and a high demand of energy-efficient lifestyles. Females and males as well as older and younger respondents show no differences in the level of information of energy saving and energy efficiency. H5 and H6 can be confirmed. Respondents with higher energy consumption and a higher income are willing to spend more money for energy saving activities and a good residential place has a higher priority than the distance to the working place, although for choosing a residential place the proximity to the workplace or the college is very important.

Between the eight investigated cities the survey found no significant differences in attitudes and awareness of the respondents. The quality of the location and the security of the location have the highest priority. Air pollution is one of the most important disturbing factors. We assess a clear attitude for an energy saving and energy efficient residential place. Most of the respondents vote for a strong extension of the public transport system.

This survey shows a picture of attitudes and awareness of a selected population segment with mainly tertiary education. Although this group is very important for the economic and social progress in India, more data and information of urban population with low income and low education, and from people from rural areas with lower income level is needed. With this data it would be possible to get a more holistic picture of attitude and awareness of energy saving and sustainability. For that purpose further research is needed, particularly for the transmission to a deeper eco-friendly education and knowledge-building and pro-environmental behavior (Vlek and Steg, 2007, Steg and Vlek, 2009, Geller 2002, Altomonte et. al., 2013). The usefulness of the value-belief-norm (VBN) theory for pro-environmental behavior analysis has been successful tested and disseminated in the psychological literature (Stern et. al., 1999).

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Perception of Indoor Temperature of Naturally Ventilated Classroom Environments during Warm Periods in a Tropical City

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ABSTRACT

According to the adaptive hypothesis, contextual factors and past thermal history modifies building occupants' thermal expectations and preferences. This paper cites the findings of a research that was based on a field investigation, for a detailed understanding of perception of thermal environments, by students, inside typical classrooms of Dhaka, Bangladesh, during the pre-monsoon (hot-dry) and monsoon (warm-humid) seasons of a year. One hundred individual responses, by subjects in naturally ventilated classrooms, provided comprehensive data, through a standard questionnaire survey, which was then used for analysis of their responses and preferences, with respect to the measured indoor thermal environment. This research revealed that thermal adversities, encountered in summer, are quite well tolerated by the acclimatized and adapted students, of Dhaka city. The findings reconfirmed that sensation, comfort and preferences about air temperature, inside classrooms of this tropical country, are markedly different from set international standards. The 'neutral' temperature of the students was identified, which was found to be much higher than the international standard. Therefore, if thermal comfort standards are contextualized, for naturally ventilated classroom spaces in Bangladesh, it is likely to minimize the pressure on energy and allow for more sustainable architecture.

Keywords: Perception, Sensation, 'Neutral' temperature, Adaptation, Classroom environment

INTRODUCTION

Any comfortable environment is a holistic phenomenon, involving synergy of thermal comfort, indoor air quality, other environmental factors, such as, the type of building and its psychological relevance for the occupants (Croome, Gan, and Awbi, 1992). According to ASHRAE 55-2004, thermal comfort is a subjective response, and is defined as the state of mind that expresses satisfaction with existing environment (Brager and Richard, 1998), which is widely driven by perception and expectation of the occupants. Therefore, the same thermal environment may be perceived differently by different occupants, or different occupants may perceive the same thermal comfort sensation for different thermal environments (Brager & Richard, 2002), (Auliciems, 1981), (Rajasekar & Ramachandraiah, 2010). While the idea of a comfortable environment for all, would involve the consideration of individual preferences, there is a set of general conditions of air and radiant temperatures, airflow, humidity, etc, in which a majority of the people would be at ease (Mallick, 1994). Thermal comfort is a key component for quality of indoor environments (Appah-Dankyi & Koranteng, 2012). Methods for defining a 'comfort zone' or 'comfort range' of acceptable temperatures are based on associating ideal conditions with a feeling of neutrality, or on conditions that are totally unnoticeable (Brager & Richard, 2002). ‘Thermal neutrality’ for a person, is the condition in which the subject would prefer neither warmer, nor cooler, surroundings (Fanger, 1972).

According to the adaptive hypothesis, contextual factors and past thermal history can modify building occupants’ thermal expectations and preferences (Brager & Richard, 1998, 2000 and 2001), while people with environmental control options, are more easily thermally satisfied, than when they perceive not to have control. Temperature and Humidity are two of the prime indicators of thermal comfort. International standards and related predictive models predict that subjects in cool climates, from where the standards have originated, feel much warmer than subjects in naturally ventilated buildings in warm climates (Tablada, Peña, & Troyer, 2005). Therefore, occupants in naturally ventilated buildings of tropical countries are tolerant of a significantly wider range of temperatures, explained by a combination of both behavioural adjustment and psychological adaptation (Brager & Richard, 1998). Such results can form the basis of indoor temperature standards, more elevated than standards set for cooler climates.

Institutional buildings mainly operate during the hottest part of the day, with young adult occupants. Research findings indicate that the thermal sensation of the younger subjects (age 22-25 year) is, in general, 0.5 scale units higher in comparison with their elderly counterparts (age 67-73 year) and that young adults prefer a lower temperature in comparison with elderly persons (Schellen, van Marken Lichtenbelt, Loomans, Toftum, & de Wit, 2010). Therefore, if the indoor environment is found comfortable for fit young adults in the summer season, then the rest of the older population will also find it to be comfortable. So, efforts should be made to predict the temperature, or combination of thermal comfort variables (air temperature, relative humidity and air velocity) which will be found comfortable in classroom environments of Bangladesh, in order to set contextual local standards.

Figure 1 Naturally ventilated classroom environments in Dhaka

The study of thermal comfort in classroom environment is very important because it directly affects students’ health and also energy consumption of the building (Markus & Morris, 1980). This paper cites a study of the classroom environment of undergraduate students in Dhaka, Bangladesh, aimed to investigate thermal sensation, acceptability and preference of indoor climatic conditions by students in naturally ventilated classroom environments, **as shown in Figure 1**, during the hottest period (April-July) of the year. During this study, five naturally ventilated classrooms were investigated on six separate occasions during the selected critical period (April-July), and the environmental data were recorded, along with responses, through questionnaires, of the subjects to these conditions. The responses were correlated with the corresponding recorded environmental data, to identify the acceptable air temperature range, along with the ‘neutral’ temperature.

Findings of such studies can lead to formation of local standards of thermal acceptability, which can result in reduction of building energy consumption.

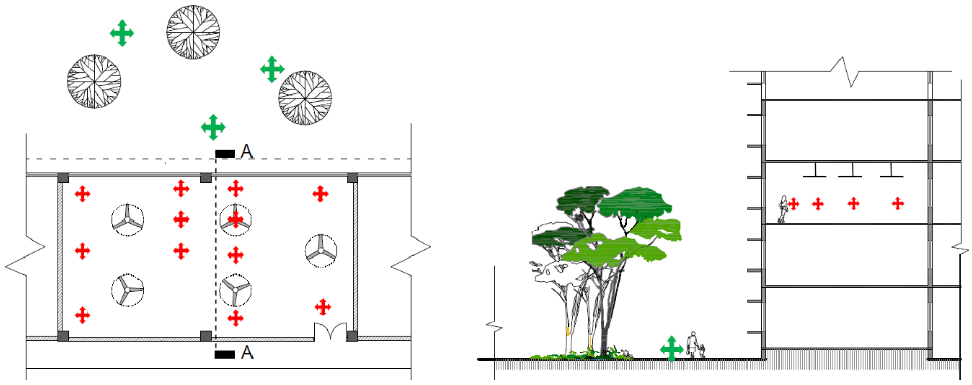
RESEARCH METHODOLOGY

Field investigation in multiple-cases, with a structured questionnaire, and measurements of simultaneous environmental conditions, was adopted as a methodology, to produce primary data during this research.

A total of 100 subjects, in naturally ventilated classrooms, of five institutions, provided comprehensive data through a questionnaire survey, on six occasions during the survey period, for the analysis of indoor thermal condition and their preferences. Transverse surveys were conducted in April, May, June and July (2013) in Dhaka, located in a tropical climatic zone.

All the selected students, aged within 18-25 years, were engaged in sedentary work, and wore summer clothing (between 0.35-0.5 clo), while all the selected classrooms had similar options of adjustment to neutralize the physiological factors affecting their thermal condition. Students had similar types of social class, as they came through the same type of educational background and set up. Naturally ventilated institutions were selected with similar materials (brick and concrete) and classrooms having glass openings were selected to get similar type of micro environment of building design.

The micro-climatic parameters were measured simultaneously during questionnaire survey, in order to relate these to the thermal responses. A Digital Thermometer Hygrometer (Zeal PH1000) was used for measuring air temperature (indoor/outdoor temperature) at positions, **as shown in Figure 2**. The airflow, mainly generated by running ceiling fans, as is common in Dhaka, was found to be on average, 0.475 m/s.



Conceptual Plan

Conceptual Section (AA)

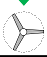
Symbol	Represents
	indoor air temperature, relative humidity, air velocity (at 01m above floor level)
	outdoor air temperature, relative humidity, air velocity (at 01 m above ground level)
	ceiling fan

Figure 2 Positions of taking measurements of environmental variables

Table 1. Thermal sensation scale (ASHRAE Scale and modified used in this research)

	thermal sensation						
ASHRAE SCALE (Fanger's Scale)	very cold	cool	slightly cool	neutral	slightly hot	hot	very hot
	-3	-2	-1	0	+1	+2	+3
Modified ASHRAE SCALE			slightly cool	neutral	slightly hot	hot	very hot
			-1	0	+1	+2	+3

Sensation Scales

A modified version of ASHRAE Scale was used (ASHRAE, 2005), **as shown in Table 1**, for measuring thermal sensation, and answering the question: ***How are you feeling (Thermal sensation)***

inside the classroom? This was because previous studies show that 'cold' discomfort is not an option in the warm seasons of Dhaka, and therefore, the options of 'cool' [-2] and 'very cold' [-3] were not mentioned in the questionnaire.

Comfort voting

The voting scale**, as shown in Table 2,** was used, to assess 'comfort', and answer the question: ***How does the classroom feel like to you (air temperature)?***

Table 2. Comfort voting of air temperature, relative humidity and air velocity

comfort voting						
uncomfortable			neutral	comfortable		
-3	-2	-1	0	+1	+2	+3

Preference Scales

To cross match comfort with preferences about air temperature, the 'McIntyre preference scale' was used (McIntyre, 1980), **as shown in Table 3**, answering the question: ***What change in the temperature do you want in the classroom?***

Table 3. Preference Scale of air temperature used in this research

thermal preference						
extreme cold	much cooler	slightly cooler	no change	slightly warmer	much warmer	extreme hot
-3	-2	-1	0	+1	+2	+3

The subjects also voted on their assessment of the environmental acceptability on subjective scales, **as shown in Table 4**, by responding to the question: ***How do you rate the overall acceptability of the thermal environment at this moment?***

Table 4. Subjective scales of 'acceptability' used in this thermal study

acceptability					
not acceptable			acceptable		
-3	-2	-1	+1	+2	+3

ANALYSIS AND RESULT

A total of 600 responses (100 students for 6 times) were investigated during the survey period, of which 251 (42%) were male and 349 (58%) were female. The measured indoor environmental parameters during the study period (April to July, 2013) are **shown is Table 5**.

Table 5. Measured indoor environmental features of selected classrooms

Measured indoor environmental features	range
Range of Mean indoor AT (ºC)	27.95 - 32.6
Range of Mean indoor RH (%)	52.5 - 80
Range of Mean indoor AV (m/s)	0.05 - 0.9

Comparison of indoor and outdoor environmental conditions

The outdoor temperature, measured at one meter (01m) above the ground level outside selected classrooms, is compared with simultaneously measured indoor conditions, **as shown in Figure 3**, showing a strong correlation, increasing and decreasing in a similar pattern.

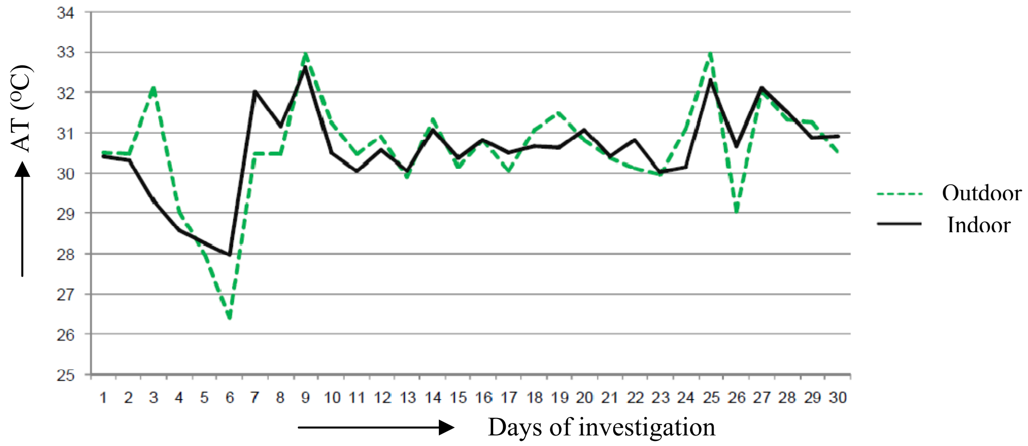


Figure 3 Comparison between indoor and outdoor air temperature (Mean)

Thermal acceptability of classroom conditions

Regarding thermal acceptability, it was found that only about 43% of the responses (257 out of 600 respondents) 'accepted' their immediate classroom environments to be comfortable. But about 73% responses lie within inside the three central categories [vote = -1, 0, +1] of the sensation scale, which imply acceptability (ASHRAE Standard 55, 2004), showing that though the respondents were not in absolute thermally acceptable conditions, the conditions were, nevertheless, close to acceptability. The mean value of thermal sensation vote (TSV) was found to be 1.003 which lies very close to the 'slightly warm' vote category [vote = +1]. But since the three central categories imply acceptability, it can be said that, in general, students are reasonably satisfied with the air temperature of their classroom.

Comfort Votes on air temperature

In order to cross check the responses of the thermal sensation scale, a question, ***How does the classroom feel like to you (regarding air temperature),*** was included in the survey, about the comfort sensation regarding the temperature experienced in the class, which varied between 27.95-32.6 ºC. For the response, a 3 point rating scale was used: Uncomfortable, Neutral and Comfortable. In this question regarding the indoor air temperature, 55% responded that their classroom condition is 'uncomfortable'. This contradicts the voting mentioned previously where 73% found conditions acceptable (voting between the -1, 0, +1 range).

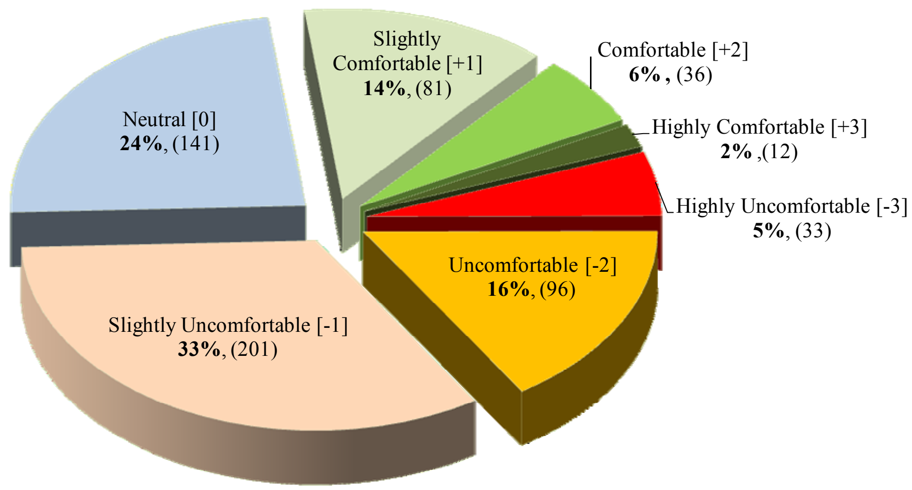


Figure 4 Comfort voting (with rating scale) regarding air temperature

But voting against a question, ***How does the classroom feel like to you (regarding air temperature),*** on a 7 point rating scale: uncomfortable degrees of -3,-2 and -1, neutral (0) and comfortable degrees of +1, +2 and +3, reveals that 71% responses were in the acceptable comfort conditions of air temperature, the students voting in between the -1, 0, +1 range**, as shown in Figure 4**.

Therefore, compared with the acceptable thermal sensation votes (73% between -1, 0, +1) and 'comfort' votes (71% within the acceptable -1, 0, +1 range), there is a close similarity between 'thermal sensation' and 'thermal comfort' due to air temperature, among these students. Moreover, on cross checking, it can be concluded that the students are aware of their environment, and that their responses to it are consistent.

Correlation between thermal sensation votes and air temperature (Mean)

The six hundred thermal sensation responses were plotted in a scatter plot diagram, against the simultaneously measured air temperatures**, as shown in Figure 5**.

The slope of this plot, generated through the computer software, reveals certain dependence between these two variables. The low R^2 value is considered indicative of the wide variability of the perception of thermal sensation vs. the actual air temperature, which is not uniform, particularly in naturally ventilated tropical spaces.

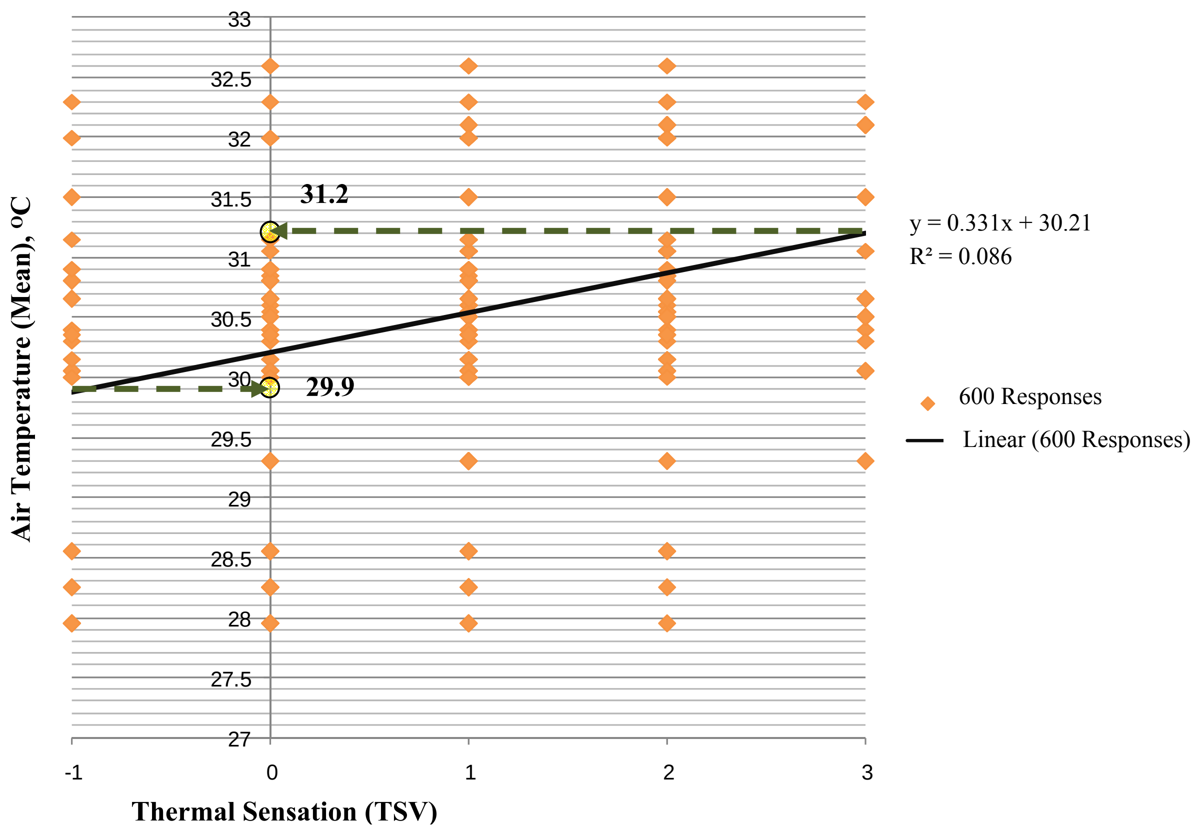
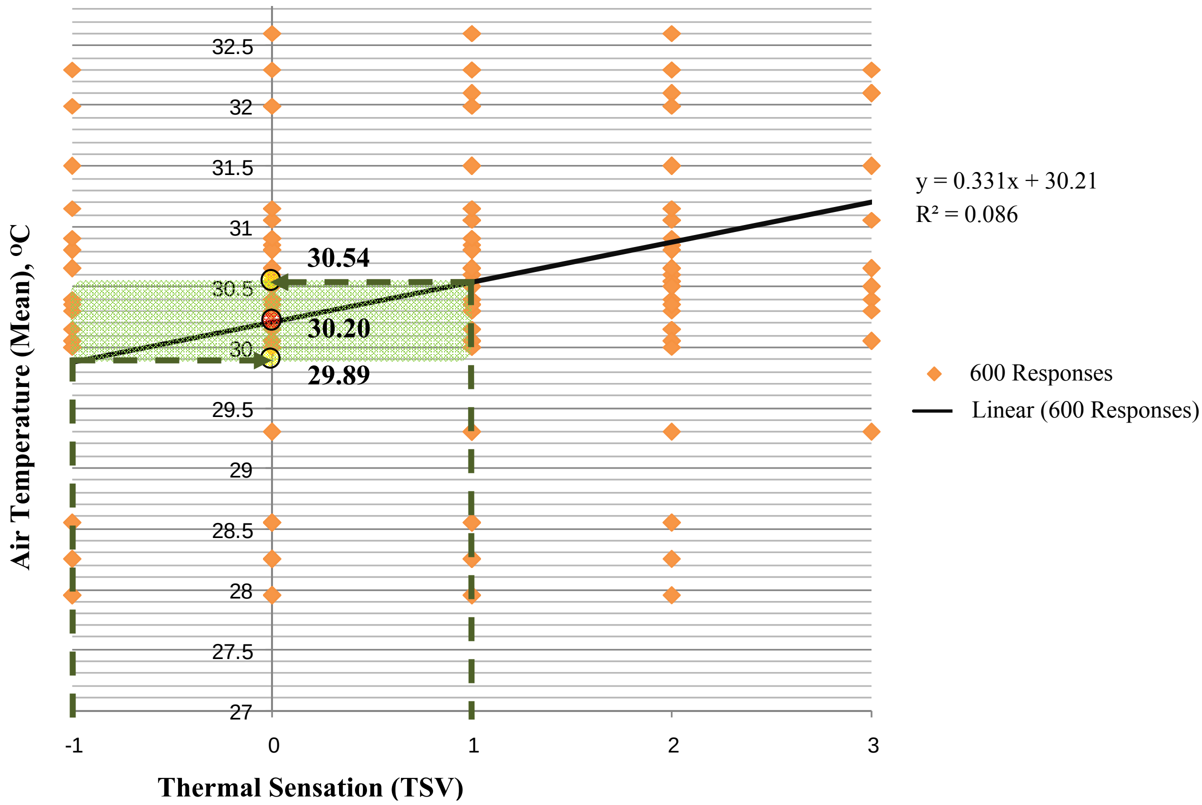


Figure 5 Thermal sensation votes VS air temperature (Mean)

This figure shows that the higher the air temperature, the higher the thermal sensation vote (TSV).When the air temperature (Mean) is 29.9 ºC, the TSV is 'slightly cool' [-1], and as the temperature rises up to 31.2 ºC, the thermal sensation vote indicates the 'very hot' [+3] condition.

Through the graph**, shown in Figure 6**, it was possible to identify a 'neutral' air temperature which may be perceived as 'neutral' by the undergraduate students (age 18-25 years) of Dhaka, Bangladesh.



Measured environmental variable during voting	Range
Range of Mean indoor AT (ºC)	27.95-32.6

Figure 6 Identification of 'neutral' temperature

The temperature range between the two lines of 'slightly hot' [+1] and 'slightly cool' [-1], forms the acceptable temperature range, (ASHRAE Standard 55, 2004), i.e. 29.89 ºC to 30.54 ºC. The intersection of the TSV Vs the Mean air temperature slope with the '0' TSV, has been identified as the 'neutral' temperature, i.e. 30.20 ºC, where the thermal sensation is 'just right'. This figure is undoubtedly much higher than that acceptable according to published international standards.

Also the very narrow acceptability range of only 0.65 degC is surprising, where thermal studies in cooler climates have revealed acceptable ranges of ±2 degC (Fanger, 1972). The reason for this is probably the high level of the neutral temperature and the state of acclimatization for the tropical population in naturally ventilated buildings.

RECOMMENDATIONS

This research concludes that, thermal adversities encountered in summer are quite well tolerated by the acclimatized and adapted students of Dhaka city. It is essential to provide a comfortable and healthy indoor environment to its dwellers in various seasons to perform their works effectively (de Dear, Fountain, Popovic, Watkins, Brager, Arens, & Benton, 1993). The neutral temperature was established at a value of 30.20 ºC, which is much higher than international standards. The findings reconfirmed that sensation, comfort and preferences of this tropical country, along with the acceptable range of temperature, are markedly different from set international standards. Therefore, developing a more relevant and contextual thermal comfort standard, for naturally ventilated spaces in Bangladesh, is an imperative, which will also accommodate different expectations, preferences and adaptation means.

Relevant thermal standards for indoor thermal conditions of Dhaka should be set on an urgent basis. As there is a very close relationship between internal temperature standards and energy usage, setting a higher acceptable temperature value will allow greater energy savings, thus allowing for a more sustainable energy balance in the country.

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Thermal Perception of Users of Different Age Groups in Urban Parks in Warm Weather Conditions

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ABSTRACT

Studies of thermal comfort in open spaces in various climatic and cultural contexts, seek to create design guidelines for attractive outdoor environments, which improve the quality of urban life. In general, these studies characterize microclimates and define the conditions for actual and/or calculated thermal comfort by predictive indexes in streets, squares and parks. In this context, this pilot study aimed to characterize the thermal perception of users and changes of the range of PET (Physiological Equivalent Temperature) for thermal neutrality according to the age of visitors to a park in the city of Bauru, State of Sao Paulo, Brazil. The study was conducted through microclimate monitoring and structured questionnaires to users in warm weather conditions. Results showed higher frequency of thermal sensation between comfortable and warm; a differential thermal preference according to the major microclimatic variations observed between morning and afternoon; little tolerance to the effect of direct solar radiation and minor differences of PET index between the age groups of children and teenagers and greater variations between these groups and adults/elderly.

INTRODUCTION

The open spaces have several ways of daily use in the city and, therefore, an important aesthetic and recreational function (Raja & Virk, 2001). Chen and Ng (2012) advocate that open spaces are key to more sustainable cities because they accommodate pedestrian traffic, the outdoor activities and contribute to the livability and urban vitality. Thus, they encourage more people to attend the open spaces in the cities benefitting their physical, environmental and socio economic dimensions.

The quest to create the most attractive open environments has contributed to the growth of research in open spaces, focused on different aspects, including thermal comfort. In this approach, the pioneering studies investigated the thermal environment, the human comfort parameters (Nikolopoulou, Baker & Steemers, 2001), the characteristics of space usage (Zacharias, Stathopoulos & Wu, 2001), the relationship between comfort psycological adaptation (Nikolopoulou & Steems, 2003), and thermal comfort and behavior patterns of users on streets, squares and parks (Thorsson, Lindqvist & Lindqvist, 2004).

These researches show the complexity of the evaluation of comfort in open spaces and proved that there is a close relationship between the thermal environment and the number and distribution of users, and also between the behavior of people in open spaces. These findings significantly influenced the development of research on the conditions for thermal comfort in open spaces in different climatic and cultural contexts (Katzschner, 2006; Thorsson, Honjo, Lindberg, Eliasson & Lim, 2007; Eliasson, Knez, Westerberg, Thorsson, Lindqvist & Lindqvist, 2004; Lin, 2009; Dacanal, Labaki & Silva, 2010; Labaki, Fontes, Bueno-Bartolomei & Dacanal, 2012 and Fontes, Nishimura, Sebastião & Faria, 2012; Lin, Lin & Hwang, 2013).

In general, these researches seek to analyze the thermal quality of open spaces, based on qualitative aspects (thermal perception of the users) and quantitatively with the use of different predictive indexes of comfort, such as the Physiological Equivalent Temperature - PET (Mayer & Höppe,1987; Höppe, 1999), to define the limits of thermal comfort. The aim is to create design subsidies that favor the creation of pleasant microclimates for human society and, consequently, contribute to the increment the daily use by the population.

So it is important that architects and landscapers use tools that have been developed from research in the area, with the goal of designing open spaces with adequate comfort conditions. Considering especially the effects of expanding cities adversely affect the microclimates of these spaces, because of the significant heat islands effects (Lin et al. 2013).

In this context, this research shows results of a pilot study investigating microclimates and thermal perceptions of users of a park located in Bauru, midsize city of São Paulo State, Brazil. However, the difference here presented, in relation to other similar studies, is to attempt to identify possible variations of PET for thermal neutrality according to the different age groups of visitors.

MATERIALS AND METHODS

Characterization of the study area

The study area is the Municipal Zoo of Bauru (Lat. 22 °18'54" S, Long. 49°03'39" W and average altitude of 530m), medium-sized city in the Midwest of São Paulo state, Brazil. According to Köppen climate classification, the local climate is Aw - tropical climate with summer marked by high temperatures and rainfalls and mild and dry winter. Figure 1 shows the thermal range of the city, from the analysis of historical data of air temperature over the period of ten years (2001-2010). The table also includes the minimum and maximum temperatures of two days of field survey in the months of October and November 2013.

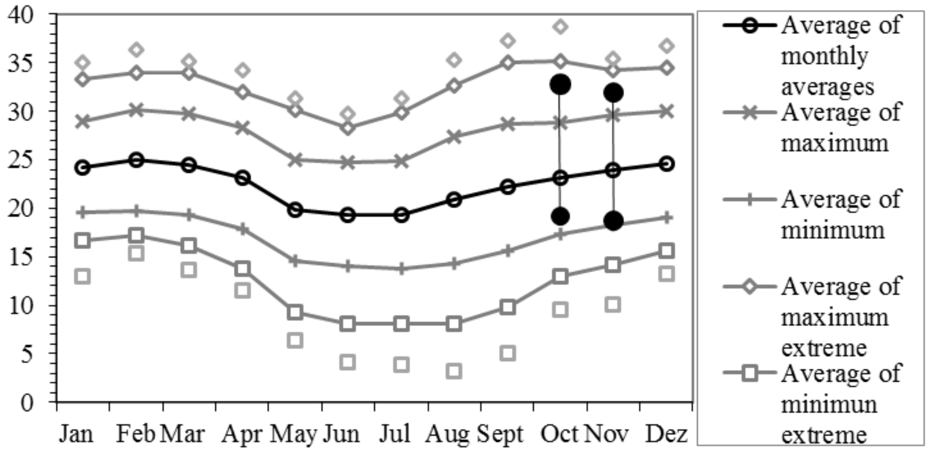

Figure 1 *Statistics of thermal data of Bauru (SP) over the period 2001-2010. Source: http://www.ipmet.unesp.br/*

The Zoo is an important recreational space for the city and region, comprising an area of 20 acres inserted into a region of cerrado vegetation of more than 200 acres (www.zoobauru.com.br). Its inner space consists of totally unshaded areas of direct solar incidence, areas partially shaded by vegetation and areas shaded by built covers, as can be seen in Figure 2 respectively.

To analyze the thermal perception of the users, one of the areas of longest permanence time within the park, "the Food Court" (Figure 3) was chosen. This place is quite shaded by vegetation and is used for relaxation and meals by users who have family picnics or to school tours. The permanence time at the site varies from a few minutes to two or three hours.

Figure 2 *Different areas of the Zoo: a) Area of felines (left) and circulation spaces, unshaded sites of direct solar incidence; b) Area of birds and local open spaces of permanence (center) partially shaded by adjacent vegetation; c) Area of primates, reptiles and penguins (right), areas shaded by built covers.*

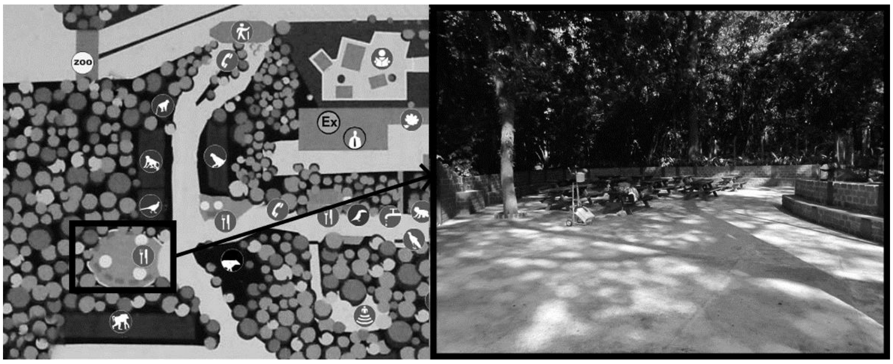

Figure 3 *Partial internal map of Bauru Zoo, especially the Food Court, site of the data collection. Adapted from www.zoobauru.com.br.*

Microclimate Monitoring

To monitor the microclimate in the food court, a mobile weather station was used with the following sensors: 1. Globe Temperature Sensor (Model 1: 0613 1712; manufacturer: Testo), built with official ping pong ball painted in gray-bourgeois (emissivity 0.9, solar reflectance 0.3); 2. Temperature and Humidity Data Logger (Model: Testo 175-H1); 3. Heated Sphere Omnidirectional Anemometer (Ø 3 mm, Model: 0635 1549; manufacturer: Testo); 4. Net radiometer (Kipp & Zonen manufacturer).

As this is a pilot study, with the aim to asess methodology for a larger project, the monitoring was carried out in just 2 days in warm weather conditions (October 26 and November 3, 2013), from 9 am until 4 pm, at intervals of 5 minutes. This Corresponds to 1 hour after the park opening team and one hour prior to its closing, During Which there is a greater number of people visiting the park.

Structured questionnaires

Structured questionnaires were applied to a sample of 115 users simultaneously to the monitoring of the microclimate. The questionnaire (Figure 4) addressed a question about the Actual Sensation Vote (ASV) on a 7-point scale, and questions about thermal preference, feeling about the wind and relative humidity. Personal data of each user were also collected: age, gender, weight, height, clothing, activity developed.

In the questionnaires, users were divided into 3 age groups: children (under 12 years), teenagers (13-20 years) and adults/elderly (over 21 years). In this division, children had some difficulty in understanding the questions and required further explanation of each question so that they could give a response that reflected their real thermal perception.

This study was unable to establish an optimal sampling in view of the lack of quantitative survey of visitors by park management. Moreover, the greater permanence space analyzed is used only by part of the users and not all park visitors. Thus, the option was to interview the maximum number of people available, coming to a final number of 115 respondents.

At the moment, what is your thermal sensation?

Very cold	Cold	Little cold	Neither cold nor warm	Little warm	Warm	Very warm

At the moment, what is your thermal preference?

Colder	Same temperature	Warmer

At the moment, what do you think about the wind?

Windless	Neither little wind nor windy	Windy

At the moment, what do you think about the humidity?

Dry	Neither dry nor wet	Wet

Do you feel comfortable?

Yes	No

Figure 4 *Part of the questionnaire applied.*

Thermal Comfort Index

In-loco surveys were used as input data of RayMan software (Matzarakis, Rutz & Mayer, 2007), to calculate the index PET (Physiological Equivalent Temperature), developed by Höppe (2002). This index is widely used in Brazilian studies (Dacanal et al., 2010; Fontes et al., 2012; Labaki et al., 2012, among others), due to the representativeness of their results, and also the ease of use by RayMan software.

For the insertion of data in the software, it was necessary to calculate the mean radiant temperature with Software Comfort 2:02 (Ruas, 2002) and also the body surface of each user, using the formula of Dubois (http://www.sbn.org. br/equacoes/eq6.htm) for the conversion of metabolic rate in W/m2 for W. Thus, the PET index was determined for each user and the following analyzes were performed: 1. Distribution of the thermal sensation frequency (ASV) and the thermal preference of users (for all users and by age group); 2. Frequency of users' thermal sensation in relation to ventilation and relative humidity; 3. Distribution of PET range for users in general and for different ages.

RESULTS AND DISCUSSION

During the fieldwork (October 26 and November 3, 2013), the data from the local weather station (IPMet) characterized the weather as hot and dry, with temperatures above the historical average for the months in question. In those days, the mornings were mild, with temperatures ranging from 23.8 ° C to 24.9 ° C at 9am in the early surveys, and reached 31.5 ° C at 4pm, end of microclimate monitoring. The relative humidity reached the highest value of 73.7% and the lowest 40% in the afternoon.

The data collected in the Food Court showed more pleasant microclimates observed in the IPMet, due to the fact that it is a place partially shaded by vegetation. The difference in air temperature in these two sites got an average of 1.4°C and reached the highest value of 2.8°C at 10:15am of the second day.

Regarding the relative humidity data the values mean monitored in zoo were until 8.7% higher than values observed in IPMet.

Figure 5 shows the behavior of the temperature and relative air humidity over the two days of measurement at fixed measuring point in the park. The air temperature ranged from 22.6 to 31.9°C and relative air humidity from 41.9 to 75.2%. The graphs show the high temperatures and low humidity in the afternoon. These data contributed decisively to thermal perceptions in this period compared to those observed during the mornings.

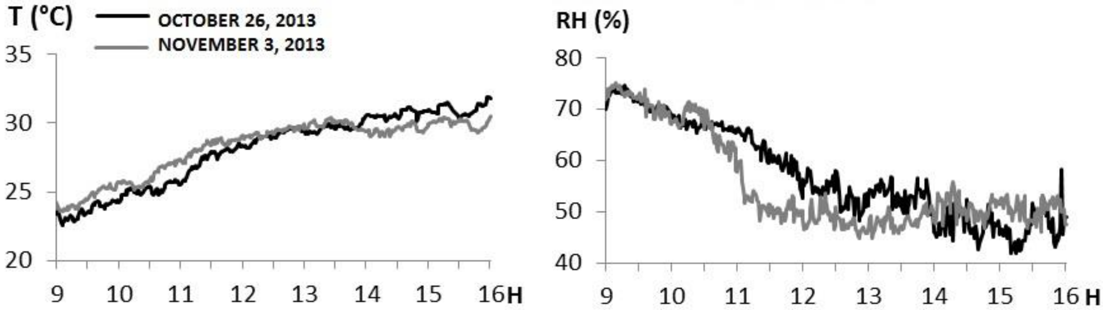

Figure 5 *Temperature and relative air humidity during the measurement days in Bauru.*

Regarding the questionnaires, the profile of the respondents had similar numbers between the genders, with 52% male and 48% female. As to age, 39% were children under 12 years, 18% of young people under 20 years and 43% of adults and elderly, with almost all wearing light clothing in view of the high temperatures of the period. 70% of the respondents were from cities in the region or further afield and only 30% were local residents.

Users proved tolerant to high temperatures, since 87% of respondents stated to be feeling comfortable (thermal satisfaction), although the thermal sensation was "little warm" or "warm." This difference between satisfaction and thermal sensation is due mainly to the influence of psychological aspects, since that was a moment of leisure in an environment surrounded by greenery. However, users have shown little tolerant to solar incidence, avoiding some of the circulation spaces with great exposure of direct sunlight. There was a tendency for users to take shelter in places shaded by vegetation, such as the Food Court, and also in areas with built roofing, instinctively seeking milder microclimates.

During the afternoon, with increasing temperature around 32°C, many users felt uncomfortable, and indicated thermal sensation of "warm". Figure 6a shows the frequency of the Actual Sensation Vote (ASV) for the period, where it is possible to observe a significant number of people in a comfortable situation, but a greater number of people feeling uncomfortable by the heat (+1, +2 and +3).

Regarding thermal preference (Fig.6b), users preferred cooler temperatures (52.2%); the same temperatures (33.9%) or warmer (13.9%). There were differences in thermal preference in relation to time of day. In the morning the users preferred the same temperature or warmer. During the afternoon, the user preference was for lower temperatures.

As for the relative air humidity, 53% of users were satisfied, 31% considered dry and 19% wet. The analysis of the periods (morning and afternoon) shows that the perception of "dry" weather was concentrated during the afternoon (42-50%) and "wet" in the morning (50-75%). However, on this variable, users were satisfied throughout the day.

In relation to the wind, 57% of users said they felt satisfied with the condition of the moment and 43% thought there was little wind. The air velocity measured was low and varied from 0.2 to 2.4 m/s. This aspect can be attributed to roughness of the vegetation. This behavior was also found in research in the woods of the city Campinas-SP, Brazil, developed by Dacanal et al. (2010). The responses on this variable showed to be very subjective. There is no clear relationship between air velocity and thermal perception of the user.

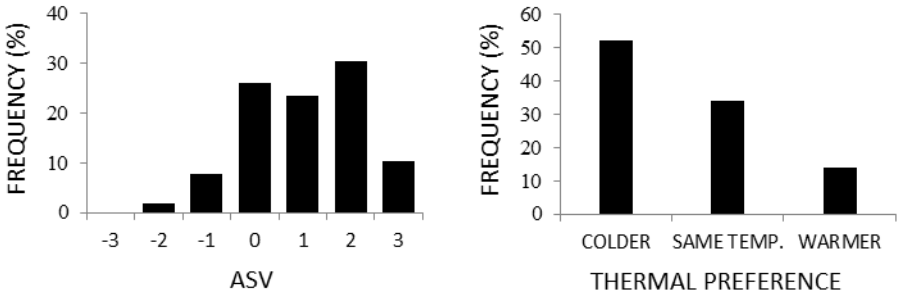

Figure 6 *Frequency of ASV and Frequency of Users' Thermal Preference, respectively. ASV.scale: -3 = very cold, -2 = cold, -1 = little cold, = 0 indifferent, 1 = little warm, 2 = warm, 3 = very warm.*

Figure 7 shows the ASV analyzed by age group (children, young people and adults/elderly). The total number of children interviewed was 45 and ASV this age group was distributed between "a little warm" (28.8%), "neither cold nor warm" (26.6%), "warm" (15.5%) 13.3% "very warm" and 2.2% "a little cold." Among young people (21 respondents), the highlight was the "hot" ASV (42.9%) and "neither hot nor cold" (33.3%). The "a little warm" scale appears with values of 14.3% and "a little cold" with 9.5%. Among adults/elderly (49 respondents), the most prominent feeling is "hot", with 38.8%, followed by "neither cold nor hot" and "a little warm", both with 22.4%. The remaining reached 4%.

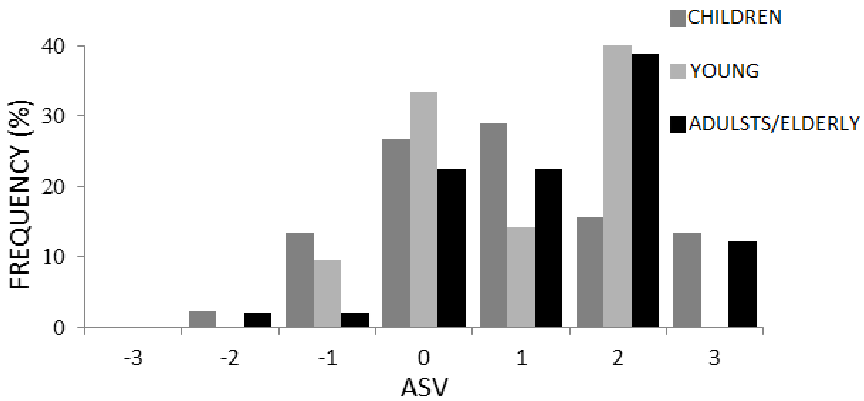

Figure 7 *Comparison of actual thermal sensation ASV between age groups.*

To define the range of comfort, the set of values of PET for each vote sensation was evaluated by means of statistical graphs Boxplot (Figure 8) which displays the PET data grouped according to the ASV, considering the total sample and the different range age (children, young people and adults/elderly). According to this graph, 50% of the central values for range of PET to the thermal neutrality were distributed between 23.5 to 29.1°C, with a median value of 25°C. This range shows values above the ones previously found by Fontes et. al (2012) for the city of Bauru (16-27 °C). However, the superposition with other intervals that indicate discomfort, either by heat or cold, makes it difficult to define precisely the limits of thermal comfort and thermal discomfort.

When analyzing the different age groups, the adults/elderly demonstrate greater tolerance to heat, with values of neutrality for PET between 25.1 to 30°C and a median value of 26.5°C. The values for the comfort range of other users are similar, i.e., they show values of PET from 23.2 to 26.5°C for children and from 22.1 to 26.7°C for young people and a median values of 24.3 and 24.1°C respectively.

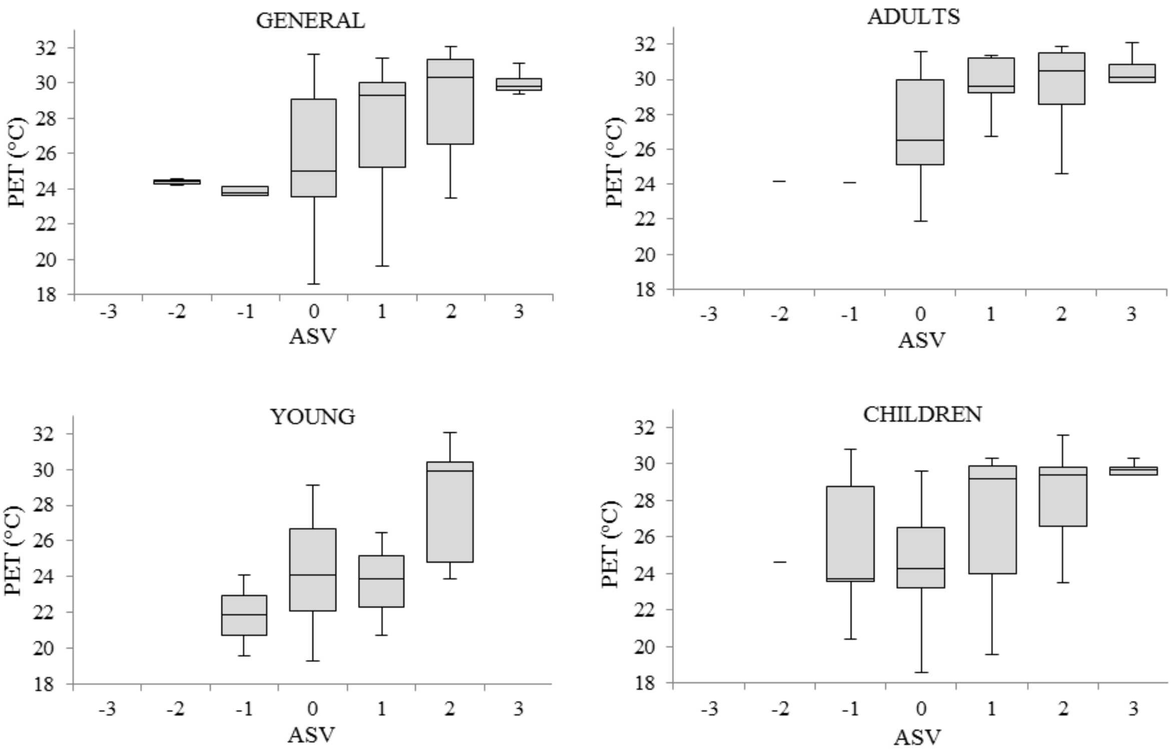

Figure 8 *Range of PET related to ASV range of the users, and separated by age group: children, teens and adults/elderlys. In the general graph, the percentage of respondents to ASV value to "Neither cool nor warm" is 26%.*

CONCLUSION

The evaluation of the thermal environment of open spaces is important to create design guidelines que can help to improve the comfort and consequently the quality of life of users. In this study, developed in warm wheather conditions, it was found que users of the park have little tolerance for direct solar incidence. Thus, for these weather conditions, future interventions shouldnt prioritize site shading, either through afforestation and / or built covers, not only in places of greater permanence, but Also in the circulation spaces.

The assessment of the Actual Sensation Votes (ASV) pointed a variation between the thermal sensation" neither cool nor warm", "little warm", "hot" and "very hot". Regarding thermal preference, most users preferred colder temperatures, specifically in the afternoon, when the air temperatures were very high (above 28 °C) and relative humidities were lower (around of 55%). The percentage of users who preferred the same local temperature was also significant.

In the microclimatic conditions evaluated, the range of thermal comfort found to PET index was 23.5 to 29.1°C for the total sample. This range shows minimum and maximum limits above those previously found by Fontes et. al (2012) for the city of Bauru (16-27 °C). In Both studies were there superposition que indicate ranges of comfort/discomfort, difficulty in proving the establishing clear limits of thermal comfort in open spaces, those already established in the literature. Regarding the analysis of the limits of thermal comfort by age groups, the differences between children and young people ranges were not significant (23.2-26.5 °C, 22.1-26.7 °C to children and young people respectively). However the differences between those thermal comfort limits and of the adult/elderly group (25.1-30.0 °C) were higher. This result shows higher tolerant to heat for that age group.

For being a pilot study, the field survey carried out in just two days was sufficient to test the methodology for the larger project that aim analyse the user thermal comfort by age group. This reasearch is unusual in surveys conducted in open spaces and can be used in architectural design in order to prioritize the needs of the largest portion of users. Thus, in the case of Bauru Zoo, an environment comfortable for children´s recreation may prevail over the other, creating more pleasant spaces and encouraging the permanence of that public.

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Environmental sustainability in scholastic facilities: an integrated assessment of building and food

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ABSTRACT

A methodology for the integrated sustainability assessment of schools facilities is presented together with its application to a case study in Milan. The study uses quantitative indicators such as non-renewable primary energy to quantify the total amount of energy used by student related to building energy consumption for comfort conditions and to food embodied energy consumed in the school canteen (from agricultural production to the cooking stage).The result is a critical review of possible sustainability improvements of the school service. In particular heating and electricity uses and food consumption are shown in the form of non-renewable primary energy. The final part describes the main improving strategies and measures their effectiveness in terms of primary energy reduction, expressed in terms of MJ per student per year of non-renewable energy. The proposed strategies include improvement measures on building envelope and on diet changes towards low energy scenarios.

INTRODUCTION

The work presented in this paper is part of the "Bioregione" research, funded by Fondazione Cariplo (www.fondazionecariplo.it). It illustrates a summary of the current state of development of the methodology Elar (Ecodynamic Land Register) with data relating to the school service.

Elar is a methodology to support energy and food integrated plans aided by application tools. The aim is to guide the suggestion of local self-sufficiency scenarios in an area defined as local (Clementi, 2008).

Thus, in accordance with the bioregional paradigm, this methodology should be used as a tool to assess the achievement of the self-sufficiency in local areas of different entity, from the municipal scale to larger areas.

The Bioregion research aims to propose different scenarios to bring together the local demand of catering and the supply potential of the region of Lombardy considering the public facilities sector.

As the school service is one of the main actors who express the collective demand for food in the regional area, Elar has been implemented in such a way as to allow the evaluation of the environmental impacts of the school service.

These activities allow the achievement of two main aims:

1. the development of different scenarios to bring together the local demand of catering and the supply potential of the region of Lombardy considering the school sector (the main aim of the Bioregion research);

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2. the development of the database to support Elar, with useful data to integrate the school service in the development of integrated food and energy plans.

All the data collected in this phase of the investigation allow to compare the energy consumption of buildings (energy consumption for heating and electricity) with the energy consumption due to the food supply chains.

In this way it is possible to assess the whole school service and to evaluate its sustainability level. Using quantitative indicators (such as the primary energy amount) and an appropriate functional unit (such as the annual primary energy consumption per student) it is possible to verify the effectiveness of different improvement scenarios.

METHODOLOGY

The main stages of Elar are the evaluation of the local demand for energy and matter and the implementation of local self-sufficiency scenarios through the adoption of best practices (stored in a specific database). The first aim is to reduce the energy and matter demand in the school sector, the second one is to better understand how the energy and matter demand could be satisfied by the local and renewable supply.

The studies conducted in the school sector reported in this text are related to the first phase, and they aim at reducing the energy and matter levies.

The ways to reduce the consumption of energy and matter in the school sector are listed in a database that shows different studies and data taken from the literature about specific best practices potentially transferable to the case studies investigated.

The transferability of good practice are related to the awareness of similar conditions related to the case study under analysis.

Considering the energy consumption of school buildings, similarities must be verified by the following points:

1. Climatic conditions (the same/similar weather conditions)
2. Use condition (the same use of the building)
3. Technological features (similar thermo-physical properties of the envelope an systems features)
4. Geometric features (similar ratio between surface and volume and between transparent/opaque areas)

Considering food consumption, similarities must be verified by the following other points:

1. Climatic conditions (to associate information on best practices about food production in the local context)
2. The number of users
3. The type of users (age of groups, etc.)

The choice of several alternatives is entrusted to impact indicators such as the accounting for primary energy and equivalent productive land (basic condition for estimating the level of local self-sufficiency).

In this first phase, the primary energy amount is the impact indicator considered.

Up to date, the applications of Elar (Clementi, Scudo, 2013) have mainly been related to the residential sector and to the population food demand and mobility.

The research presented in this text deals with the evaluation of integrated services focusing on the school service.

Future insights will be related to other types of services, such as health services, sports and public administration in order to have a most comprehensive scenario of all the activities that have taken place in the area under analysis.

Following the general steps of Elar, the next part of the text is organized as below:

1. Information about the energy consumption of the school sector in Italy is presented;
2. The case study and its energy/matter demand during a year is shown (considering all its

energy consumption);

3. information on best practices for upgrading school buildings is shown, highlighting the possibility of reducing the energy consumption and the ability to use renewable energy (such information is stored in the Elar database of good practices)
4. some of the possibilities to reduce the demand for energy and matter relating to the food supply system are suggested;
5. in the final part of the text, an integrated assessment of the effectiveness of the strategies is shown, identifying the relative weight of the different strategies on the total non-renewable primary energy consumed per student each year.

THE ENERGY CONSUMPTION OF SCHOOL BUILDINGS IN ITALY

The overall energy consumption of all the Italian public schools (representing approximately the 85% of the total energy consumption in the schools sector) and private schools, was estimated at 990,000 Tep/year, of which 762,000 of fuel for heating and 228,000 of electricity.

Italians schools consist on 62,217 buildings and they comprise up to 8,845,213 students.

In the Italian case, considering that a Tep is equal to 11,630kWh, the fuel consumption would amount to 886,060 MWh and the primary energy consumption for electricity would be equal to 2.65164 million of MWh.

The contribution per student in Italy would amount to 1,002 kWh / student = 3,606 MJ / student and electricity consumption is equal to 299 kWh / student/year = 1,079MJ

Dividing this last value by the efficiency of the national electricity system (45,9%), it appears that the annual electricity consumption per student amounts to 137kWh/year. The total energy consumption for the school service in Italy amount to 4,685MJ/student.

THE CASE STUDY: A SCHOOL BUILDING IN MILAN

The case study is a primary school building in a district in the east side of Milan. It houses 300 students and it is occupied in the morning and in the afternoon from Monday to Friday (from 8am to 5pm)

Figure 1, 2. Aerial view of the school in Milan taken as case study (source: Google Maps) and view of the south façade.

Climatic factors

Degree days 2,404 (comfort temperature: 20°C)

Annual solar radiation incident on a horizontal surface: 1,450 kWh/ m^2

Geometrical features

Floors above ground: 3

Eaves height: 15 m

Net area: 4,362 m^2 (the total area amounts to 14.6 square meters per student)

Value of S/V of the building: 0.38

Technological features

The opaque vertical envelope is composed of two types of both full plastered brick, the first one covers 4,290m^2, the thickness is 17cm, the thermal transmittance is 1.34 W/m^{2}K; the second one constitutes the masonry spandrel and it covers 520 square meters, the thickness is 43cm, the thermal transmittance is 2.46 W/m^{2}K .

The vertical windows are composed of wooden frame with single glazing and they cover 1,341m^2, the thermal transmittance is 5.7 W m^{2}K.

The total vertical surface amounts to 6,151mq, so the transparent surface occupies the 22% of the total vertical surface. The part of the opaque envelope with higher value of transmittance amounts to 8, 5%. The thermal trasmittance of the covering amounts to 1 W/m^{2}K, of the ground slab 0.7 W/m^{2}K

Energy Consumption for heating in winter

The building annually consumes 146 kWh/m^2 of natural gas. Since the square meters per student amount to 14.6 m^2, the per capita consumption of non renewable primary energy is 2,132kWh/student, equal to 7,673MJ/student.

Electrical consumption

Breaking down the energy consumption of the building the following items emerge:

- power consumption of the heating plant: 12,500kWh (29%)
- personal computer: 7,500 kWh / year (18%)
- Copiers: 1,000kWh/year (2%)
- washing machine: 400kwh/year (1%)
- Lighting system: 21,000 kWh (50%) ..

Adding together all the components, the total energy consumption for the building is equal to 42,400kWh of electricity, equal to an amount of non renewable primary energy of 1,107MJ per student.

ENERGY UPGRADING STRATEGIES ON THE BUILDING

The assumptions relating to the possible ameliorative actions to reduce energy consumption of the building were chosen among similar cases in the database of Elar. The Pirandello primary school in Moncalieri (province of Turin) was adopted as case study, cause of similar climatic conditions and similare geometrical and technological features.

Climatic factors

Degree days 2,553 (comfort temperature 20°).

Annual solar radiation incident on a horizontal surface 1,470 kWh/m^2

Geometric factors

Floors above ground: 3

Gross surface area of 5,049 m^2

Value of S/V of the building: 0.35

Vertical dispersant surface 3,363 m^2,% of total glazed area of the vertical surface 30%.

Technological factors

Opaque vertical envelope transmittance of walls 1.45 W/m^{2}K, transparent surfaces 6.1 W/m^{2}K, covering 0.31 W/m^{2}K, ground slab 1.44 W/m^{2}K.

Energy consumption before the intervention

The real energy consumption for heating in the case of Pirandello school is 759,069 kWh, the gross volume amounts to 19,441 cubic meters, so the real consumption per cubic meter would be 39 kWh, similar to the value of the school of Milan. In this latter case the actual consumption amounts to 146kWh/mq considering the net height of each floor of 4 m, the consumption for each cubic meter would amount to 36.5kWh/m^3.

Energy upgrading strategies on the building

The actions proposed in the case of Pirandello school in Moncalieri, are extracted from the data published by Silvia Tedesco (Tedesco, 2010) and consist solely of measures to improve the performance of the building envelope. They provide insulation of the ground floor, the insulation of opaque vertical external envelop, roof insulation and replace the tansparent parts with double-glazed windows with low-emittance layer, thermal transmittance 2W/m^2K.

In the case of the vertical opaque the upgrading intervention was hypothesized to isolate the masonry from the inside with polystyrene pre-coupled panels and plasterboard, not to lose the aesthetic connotation given by the presence of the elements in the facade. The implementation of this intervention guarantees a reduction of the heat dispersions for transmission greater than 60%. The thickness of the insulation measures 5 cm and 1 cm plasterboard.

The estimated reduction in primary energy consumption result of the proposed actions would amount to 65% of total consumption, going from 53.52 kWh/m^3*year to 18.61 kWh/m^3*year (theoretical continuous operation).

In the case in Milan adopting the same types of intervention consumption for heating could be reduced by the same percentage, then passing from 146 kWh /m^2 to 51kWh/ m^2, the contribution per student would therefore decrease from the current 7,673MJ/year to 2,686MJ/year.

STRATEGIES TO REDUCE ELECTRICITY CONSUMPTION

An additional intervention to reduce energy consumption could be provided replacing the lighting systems with LED lamps instead of fluorescent lamps. By adopting this solution, the actual consumption of 21,000 kWh would be reduced to 16,800. Such a calculation was performed by estimating an efficiency of 85 lumens/watt, compared to 65 lumens/watt related to fluorescent lamps. The reduction in consumption would amount to 20%, it would affect 10% of total electricity consumption (electricity s1 in Figure 4).

Considering the orientation of the building the installation of a photovoltaic system on the roof can be an effective solution. The system could perform energy exchange with the local power grid. One square meter of PV system tilted at 15 ° and facing south, allows the production of about 150 kWh of electricity (solar values extracted from the "pvgis" solar atlas with a safety margin of 5%, www.re.jrc.ec.europa.eu/pvgis/), the production of 141 kWh of electrical energy per student would require the installation of 0, 94 square meters per student of PV polycristalline collectors with the same orientation and tilt. 282 square meters of photovoltaic panels are therefore needed on the roof. The surface of the roof slopes facing south is sufficient to accommodate such an amount of solar panels, consequently, the balance between the consumption and the production of electricity in a year will be equal to 0 (electricity s2 in Figure 3).

ENERGY FOR FOOD SUPPLY AND CONSUMPTION

After noting that the number of students in the school is 300, estimation of food demand relative to meals eaten at school was carried out as follows:

The type of food in terms of the proportion of each type compared to the total mass was derived by taking the same proportions determined from the total food purchased in the urban area of Milan by the public school canteens (Spigarolo, 2014). The main foods between those consumed each year were taken into account , particularly those whose weight consumed per year per student exceed 1 kg (Table 1).

Table 1. Amount of food consumed annually by each student in the school canteen (only quantities exceeding a kg were considered) and primary energy.

Data sources related to the primary energy content associated to each food are reported in the references in the following order (a: Mila I Canals et al., 2008; b: Assomela, 2012; c: www.lcafood.dk; d: De Cecco, 2010; e: Karakaya, 2011; f: Gonzales et al, 2011)

Foods	kg/year*stud.	Primary energy, only food production MJ/year	Primary energy for cooking MJ/year	Data sources
Frozen vegetables	6,05	121,09	33,30	a
Apples	8,00	26,80	0,00	b
Bread	10,59	105,90	0,00	c
Bananas	6,89	37,20	0,00	c
Potatoes	10,16	9,85	55,87	c
Yogurt	4,13	15,52	0,00	c
Oranges	2,62	8,77	0,00	c
Carrots	6,54	11,05	35,95	c
Pears	3,06	10,25	0,00	c
Lettuce	1,96	3,32	0,00	c
Lettuce out of season	1,96	98,21	0,00	f
Pasta	8,13	127,65	44,72	d
Zucchini	3,88	6,55	21,32	c
Eggs	2,06	18,88	11,33	c
Rice	3,24	22,03	17,82	c
Tangerines	2,82	9,44	0,00	c
Poultry meat	5,20	91,53	28,60	c
Tomato sauce	1,86	18,91	10,20	e
Beef	2,45	191,31	13,50	c
Olive oil	2,57	61,59	0,00	c
Fresh cheese	3,51	155,63	0,00	c
Tomato	1,22	3,66	0,00	f
Tomato out of season	1,22	61,07	0,00	f
Milk	3,40	12,78	0,00	c
Fennel	2,66	4,50	14,63	c

The estimate concerning the non-renewable primary energy demand for food has been carried out using data from the scientific literature covering the main part of the food chain from production in the field up to the cooking. The stage of waste management are excluded from the counting. The table in figure 3 relates the annual food consumption to the amount of non-renewable primary energy used for the food production and cooking. To estimate the contribution of energy for cooking, the same value for all food cooked was adopted (equal to 5.5 MJ / kg), as an average value between the available data on cooking of vegetables, pasta, rice and meat (Carlsson Kanyama et al, 2001).

The total non-renewable primary energy consumed annually by each student for food consumption amounts to 2,127 MJ/year.

SCENARIOS TO REDUCE THE ENERGY CONSUMPTION IN FOOD DEMAND

The diet proposed to reduce energy consumption related to food demand consists of the following strategies:

1. Replacement of frozen vegetables with seasonal vegetables.
2. Replacement of vegetables produced in greenhouses with seasonal vegetables.
3. Replacing beef with chicken meat.
4. 50% reduction in protein intake from animal foods and replace them with foods of vegetal origin characterized by the same amount of protein.

To assess the relative weight of each action on the total, various scenarios are formulated. They allow to verify the contribution of different strategies to weigh the relative reduction compared to the total.

The first concerns the elimination of frozen vegetables, replaced with seasonal vegetables. The percentage reduction compared to the total primary energy used for feeding amounts to 7.3%.

The second adds to the strategies of the previous scenario the elimination of the vegetables grown in greenhouse, replacing them with seasonal vegetables. The percentage reduction compared to the total primary energy used for feeding increases to 17.4%.

The third suggests to replace beef with chicken meat: the percentage reduction compared to the total primary energy used for feeding increases to 26.9%.

The fourth is a further improving effect of the scenario 3 and foresees the replacement of 50% of the proteins derived from animals, (poultry meat and dairy products) with proteins of vegetal origin (in this exemplary case legumes). The percentage reduction compared to the total primary energy used for feeding increases to 30.6%.

CONCLUSIONS

Performing an assessment of the aggregate possible strategies, it appears that the use of non-renewable primary energy per student may be reduced by a percentage equal to 63.7%.

In summary it is the result of a 65% reduction in fuel consumption for heating due to energy efficient refurbishment of the building, a neutral electricity budget achieved through the installation of a photovoltaic system on the roof, and a reduction of the energy used to produce the foodstuffs consumed in the school canteen at 30.6%.

As mentioned in the introduction the experimental approach adopted in this study is aimed at the creation of tools to support the achievement of self-sufficiency at the local scale, through the development of integrated food and energy plans.

The spread and development of this approach are closely related to the intention by public institutions and local communities to build more resilient regional systems, based on the use of locally available resources and less dependent on fossil fuels.

The calculation of non renewable primary energy applied to all consumption categories that characterize the service provided is therefore a first essential step in this direction. The next step has not been treated in this text and has been presented in other publications (Scudo et al., 2013), it concerns the attachment to the primary energy accounting of the extension of local land needed to produce the food and renewable energy sources, intended as potential energy supply.

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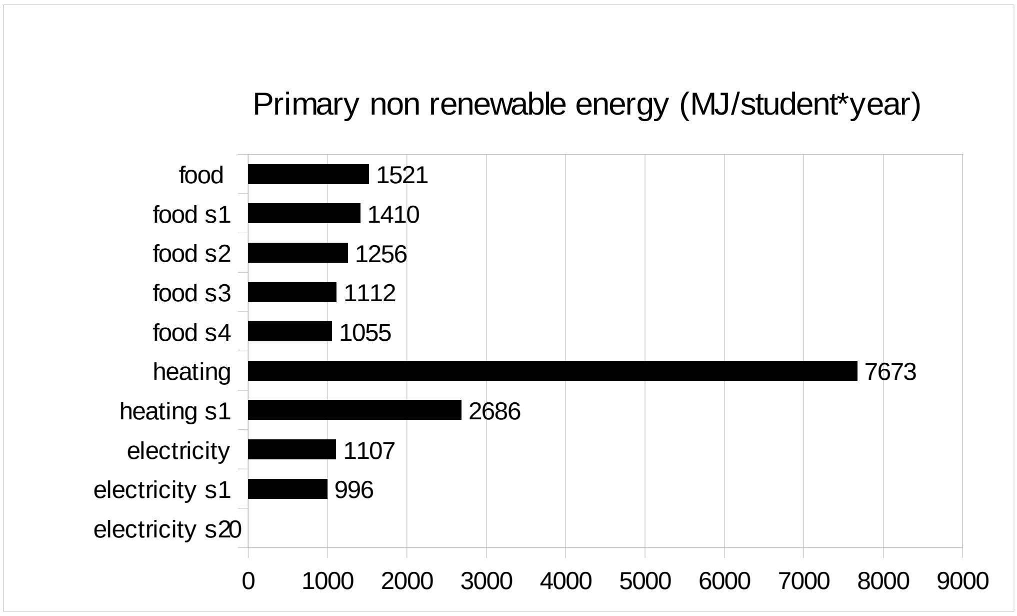

Figure 3. Comparison among items that constitute the total non-renewable primary energy per student per year. Items followed by the letter "s" refer to the improved solutions proposed in the scenarios presented in the text.

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Towards Sustainable Modular Housing: A Case Study of Thermal Performance Optimisation for Australia

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ABSTRACT

The need for affordable housing is a growing issue requiring sincere and urgent attention globally. With increasing focus on climate change and other environmental issues our housing must be environmentally sustainable too. We also need housing in remote areas where conventional construction is both cost and resource inefficient. Prefabrication offers great opportunities for both sustainability and affordability and hence is emerging as an attractive alternative to conventional on-site construction.

In this context, the CRC for Low Carbon Living in Australia has been engaged to develop designs for sustainable and affordable modular homes. The early optimisation was undertaken using AccuRate Sustainability – Australia's national benchmark software tool for rating the thermal performance of residential designs. An iterative process was employed where the rating software was used as a design and analytical tool to generate optimised designs for various orientations and climate zones throughout Australia. This paper explores the process of improving the performance of an existing design and developing a thermally optimised new design, and presents some of the early results of this optimisation.

The results show significant improvements in the thermal performance when compared to the existing design, but more importantly, the combined engineering and design research efforts developed general design principles that seemed to work well for most of the climates and orientations studied. This research contributes to the debate on integrative design process and its significance for sustainable built environment in general; it also ascertains the path forward for a more comprehensive approach to net zero energy and self-reliant modular housing – the eventual aim of the project.

INTRODUCTION

The need for adequate affordable housing is now considered a major issue in both industrialised and emerging countries (St Andrews Centre for Housing Research et al., 2014). With increasing focus on climate change mitigation and adaptation along with other environmental concerns these housing solutions need to be environmentally sustainable too. Both in Australia and overseas prefabricated housing solutions have been identified and are being proposed as an important path that can deliver both sustainable and affordable housing (Quale, 2012; The Greens, 2013). There is also a significant need for adequate solutions for remote area housing (regional communities, mining towns, emergency shelters, etc.) where conventional on-site construction is both costly and resource inefficient. Off-site construction or prefabrication in such situations becomes an especially attractive alternative.

In this context a multidisciplinary research team at the Cooperative Research Centre for Low Carbon Living (CRCLCL) has been engaged by Nova Deko, a modular housing manufacturer, to develop design solutions for 'Sustainable and Affordable Living through Modular, Net Zero Energy, Transportable, and Self-Reliant Homes and Communities'(Low Carbon Living CRC, 2014). The project is currently in its second year and this paper explores the recently completed first stage of this project – improving the operational performance of an existing design – and discusses the process of developing a thermally optimised new design for sustainable modular housing as per Nova Deko's requirements.

This paper presents the findings from the early thermal performance optimization process – a combined engineering and architectural design research effort – that started with the original design called 'Samara Pod' and finished with the creation and optimization of the final improved design called 'conceptPod'. An important part of this process was the well-designed integration of various services including domestic hot water, photovoltaic (PV) system, electrical services, equipment, white goods, and rainwater harvesting. The reason for this was twofold. First, to achieve a standardised and integrated product, so the installation of the complete Pod is easier, quicker, and therefore more cost effective. Second, to apply whole systems thinking during thermal performance optimization so the final design was efficient not only operationally but also throughout its lifecycle. In order to maintain the focus on the subject matter and in response to the space limitations here, however, the research on PV and other services integration is considered out of scope for this paper. The research presented here is a work in progress and achieving a net zero energy or self-reliant status, the eventual aim of the project, will be subject to further optimisation and renewable energy, water and waste system integration.

METHODOLOGY

The research for the project began with a study of literature on theory and practice of prefabrication and then employed an ongoing collaborative and integrative design process. The optimisation was performed as an iterative process using AccuRate Sustainability, a Nationwide House Energy Rating Scheme (NatHERS) accredited software, which measures thermal performance based energy efficiency of residential designs in Australia (CSIRO, 2014). The software, from here on referred to simply as AccuRate, was tested and validated using the Internation Energy Agency BESTEST protocol and was found to be very satisfactory (Delsante, 2005). During simulation AccuRate automatically switches between mechanical air conditioning and natural ventilation modes to maintain indoor thermal comfort within parameters specified by regulatory requirements. In doing so it calculates heating and cooling demands to maintain comfort conditions over a whole year. The total annual energy load (MJ/m2) expresses the overall thermal performance in a star rating for the specified climate zone. The rating ranges between 0 and 10 starts where a 0-star indicates the building envelop practically having no effect in reducing thermal discomfort while at 10-star performance the occupants are likely to need little or no mechanical cooling or heating to maintain comfort (Ren et al., 2013).

The National Construction Code's Building Code of Australia (BCA), in the absence of any specific state level regulations, requires all new houses to meet the minimum thermal performance of 6-stars for their regulatory approvals. Considering that the subject design will anyway need to be rated for regulatory compliance and that AccuRate has robust modeling capabilities to use it as a design decision making tool the research team decided that AccuRate was a very suitable tool for this particular research. The objective was to achieve as high a start rating as possible thereby minimising the size of a PV system to offset the remaining energy requirement.

The scope for this study included five key climate zones from Australia and eight orientations for each zone. The iterative process was designed so that the pod design and its thermal performance was improved to a satisfactory level for one climate and then that optimized design was used as the base model for improvement in the following climate, and so on. The idea behind this was to test if the "good design principles" applied in one climate could serve as a good starting point for a similar climate. To apply this approach the researchers used the following climate sequence: Brisbane, Sydney, Melbourne, and Hobart, i.e., from North to South, or warm to colder climates. Finally, the climate of Darwin, which is located further north, was also tested taking Brisbane results as the base model.

The process was essentially a parametric study where three key strategies – shading, insulation and glazing – were tested and parameters, such as type, position and amount of glazing, shading and insulation, were changed individually in order to reach local and global optimums. Although this required several iterations, due to space limitations only the first and the last simulation results are presented here. Three main types of shading devices tested were fixed horizontal, fixed vertical (wing walls), and "operable shading" such as operable louvers or sails. The performance of several types of glazing options were analysed mainly based on their U-value (W/m^{2}K) and solar heat gain coefficient (SHGC) value. Different types and levels of insulation based on their R-values (m^{2}K/W) were also tested for each location. As a general principle, the level of insulation was maximized and glazing was reduced, while trying to maintain good cross ventilation and connection with the outdoors. The optimization was finalised when no further meaningful improvements in the thermal performance (measured by star rating from the AccuRate simulation) could be achieved by modifying Shading, Glazing, and Insulation.

Changes in other parameters of the design were scheduled for the next stages of the project and hence were considered external to the scope for this particular exercise. Nevertheless, design quality and aesthetics of the interior spaces and the exterior, services and technology integration, weight of the completed Pod, and non-thermal environmental concerns were always part of the consideration even if they are not elaborated on in this paper due to space limitations. In every climate the simulation was started with the orientation of the front façade with bi-fold doors at the North before testing other orientations. The exposure was kept Suburban and ground reflectance as 0.2 in all AccuRate simulations.

EXISTING DESIGN AND ITS PERFORMANCE

The study started by taking the existing design of Samara Pod as the base model for Brisbane. The house with a simple rectangular floor plan (Figure 1) is manufactured with lightweight steel framing in a wide 40 foot shipping container size. The design has been developed so that a nearly complete house would be shipped to any site. With minimum onsite assembly requirements, except when other external features such as outdoor deck and additional shading were required, the house would be ready to occupy in a matter of days after arriving on site (Figure 2). The first AccuRate simulation was based on material specifications listed in Table 1 and produced a rating of 5.1 stars with detailed results tabled in Table 2.

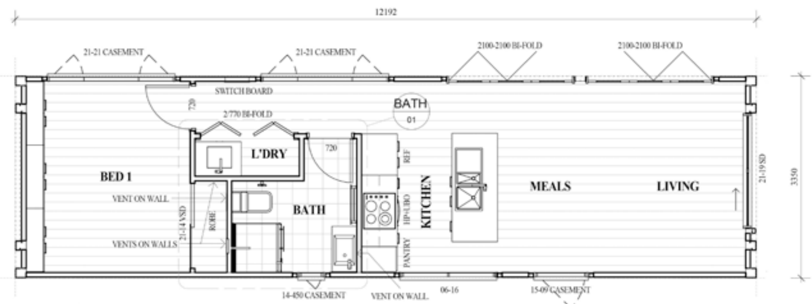

Figure 1 Floor plan of Samara Pod Base Model (Source: Nova Deko)

Figure 2 Samara Pod viewed from the North (Source: Nova Deko)

Table 1. Specification of Samara Pod Base Model

Element	Construction	R value (Up/Dn)
External wall	FC board/Reflective Barrier/Insulation/Plaster Board	3.38 / 3.38
Internal Wall	Plaster Board/Air Gap/ Plaster Board or FC board	0.44 / 0.44
Roof/ceiling	Steel/Ref. Barrier/Insulation/Plasterboard	4.12 / 4.35
Floor	Timber/FC board/Insulation	3.05 / 3.05
Windows	Glass/Air Gap/Glass; SHGC = 0.48; U = 3.92	0.25
Shading	As per Samara Pod (900mm North, 320mm rest)	NA
Underfloor	Enclosed 500mm height subfloor	NA

PERFORMANCE OPTIMISATION ACROSS DIFFERENT CLIMATES

Brisbane is located in a subtropical (no dry season) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). The performance of the base model in Brisbane indicated disproportionate energy use in cooling. To address this issue main priority was given to reducing the amount and altering the type of glazing to reduce heat-gain. Through intense integrative design exercises a series of changes were identified and simulated. This included minor modifications to the internal layout mainly to redesign the bathroom and laundry to achieve better integration of various services. Key changes were in the building envelope for strategic placement of a mix of different types of high performance glazing (U=1.5 and SHGC=0.5 or less) especially on the East and West, and various types of shading devices especially on the North. With the help of these changes the optimised design – the conceptPod – was finally able to achieve 7.6 stars with total energy demand reduced to about 55% of the Base Model when the glazing area to floor area ratio was reduced to about 52% from the original 64%.

Table 2. Thermal Performance Improvement of conceptPod Base Model in Brisbane

Description	Heating (MJ/m^2)	Total Cooling (MJ/m^2)	Total Energy (MJ/m^2)	Rating (Stars)
Base Model conceptPod	12.3	41.0	53.3	5.1
Optimised conceptPod	10.3	19.2	29.5	7.6

As discussed earlier the conceptPod for Brisbane was taken as the Base Model for Sydney, which is located in a temperate (no dry season – warm summer) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). The simulation for Sydney rated the design at 7.0 stars. Several modifications were made to the design, mainly shading and wing walls size and positions, but the best results were obtained with operable shading to the North allowing winter sun in the living areas and the bedroom, and deep shading in the form of a carport to the East. This gave a rating of 7.9 stars (Table 3).

Table 3. Thermal Performance Improvement of conceptPod Base Model in Sydney

Description	Heating (MJ/m^2)	Total Cooling (MJ/m^2)	Total Energy (MJ/m^2)	Rating (Stars)
Base Model conceptPod	12.7	17.1	29.9	7.0
Optimised conceptPod	7.8	15.2	23.0	7.9

Melbourne has a temperate (no dry season – warm summer) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). When the optimized design for Sydney was tested for Melbourne, it rated at 6.9 stars, a decrease of 1 star compared with Sydney. A large number of changes in shading, glazing size and insulation were made without any significant improvement to the overall performance. It was only after converting most of the glazing into high performance glazing equivalent to top of the range double glazed windows that the rating of the Pod increased to 7.7 stars (Table 4).

Table 4. Thermal Performance Improvement of conceptPod Base Model in Melbourne

Description	Heating (MJ/m^2)	Total Cooling (MJ/m^2)	Total Energy (MJ/m^2)	Rating (Stars)
Base Model conceptPod	59.0	27.3	86.3	6.9
Optimised conceptPod	36.6	27.0	63.6	7.7

Hobart has a temperate (no dry season – mild summer) climate as per a modified Koppen classification (Bureau of Meteorology, 2012) and has a large proportion of energy use in heating spaces. Surprisingly, when the Melbourne design was simulated in the Hobart climate the obtained rating was, already higher than Melbourne, at 8.1 stars. A similar result was obtained with the base Samara Pod, which achieved a 6.0 star rating, highest so far of all tested climates. Because the obtained rating with the conceptPod was already above 8 stars, the optimization for this climate was based on obtaining the best rating possible while limiting the standard double glazing in the main windows for the living area and the bedrooms. Finally, with strategically placed high performance glazing and carefully sized and positioned operable horizontal and vertical shades the final design resulted in a rating of 7.6 stars.

Table 5. Thermal Performance Improvement of conceptPod Base Model in Hobart

Description	Heating (MJ/m^2)	Total Cooling (MJ/m^2)	Total Energy (MJ/m^2)	Rating (Stars)
Base Model conceptPod	64.0	4.6	68.6	8.1
Optimised conceptPod	82.1	7.1	89.3	7.6

Darwin is on the other end of the climate spectrum when compared to Hobart. It is located in the tropical (Savana) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). Because of its proximity with the equator, the sun here can be in the South (summer) as well as in the North (winter). This meant that shading on both of these façades had to be considered very carefully. For this climate the optimized Brisbane Pod was taken as the based model. The first simulation showed a rating of 5.9 stars, the lowest rating obtained so far for any first iteration. After several changes, without much improvement, the highest rating of 7.2 stars was obtained when all Northern windows were made high performance glazing equivalent to triple glazing, insulation was maximized everywhere and 450mm fixed horizontal shading, similar to an eave, was added to all facades. However, the aesthetics of this solution remained unresolved with an intention to revisit the design and thermal performance improvement strategies employed in this climate. The maximum rating of 7.2 stars is the lowest achieved for all climates after the optimization and may be indicative of the limits of the current Pod design, its size or the small number of improvement strategies tested so far.

Table 6. Thermal Performance Improvement of conceptPod Base Model in Darwin

Description	Heating (MJ/m^2)	Total Cooling (MJ/m^2)	Total Energy (MJ/m^2)	Rating (Stars)
Base Model conceptPod	0.0	356.8	356.8	5.9
Optimised conceptPod	0.0	275.3	275.3	7.2

ORIENTATION SENSITIVITY ANALYSIS

The designs of Samara Pod and climate optimised conceptPods when simulated for all five climate zones across eight orientations they produced results as illustrated in Figure 3. The Brisbane results show that the conceptPod performs relatively well (above or close to 6 stars) for five of the eight orientations, mainly between North and East. The performance decreased markedly when the Pod was oriented to the South and West, with the West having the lowest thermal rating (4.7 stars) due, not surprisingly, to the increase in required cooling. The overall performance of the conceptPod showed improvements between 1.5 to 3.0 stars when compared to the Samara Pod. It is important to notice that the conceptPod design not only achieves a better rating, but is also more resilient to orientation changes.

Similar to Brisbane, in Sydney the conceptPod performs consistently 2 to 3 stars better than the base Samara Pod. In this case however, the performance penalty in the west and south orientation are less pronounced, with a minimum rating of 5.8 stars when facing west. This is an encouraging result as it shows a greater flexibility and resilience of the design to orientation changes. The conceptPod achieves near or above 6 stars rating across all orientations.

The results of the simulations show that orientation has lesser effect in Melbourne than in Sydney or Brisbane. This supports the hypothesis that in Melbourne the thermal performance is dominated by the R value of the envelope and quality of windows, instead of the solar gain. The Pod performs very well in all the orientations, with a minimum rating of 7.0 stars for the West orientation. This is also true for the base Samara design which obtains a more consistent performance for all orientations. The conceptPod performs consistently around 2.5 stars better than the base Samara Pod.

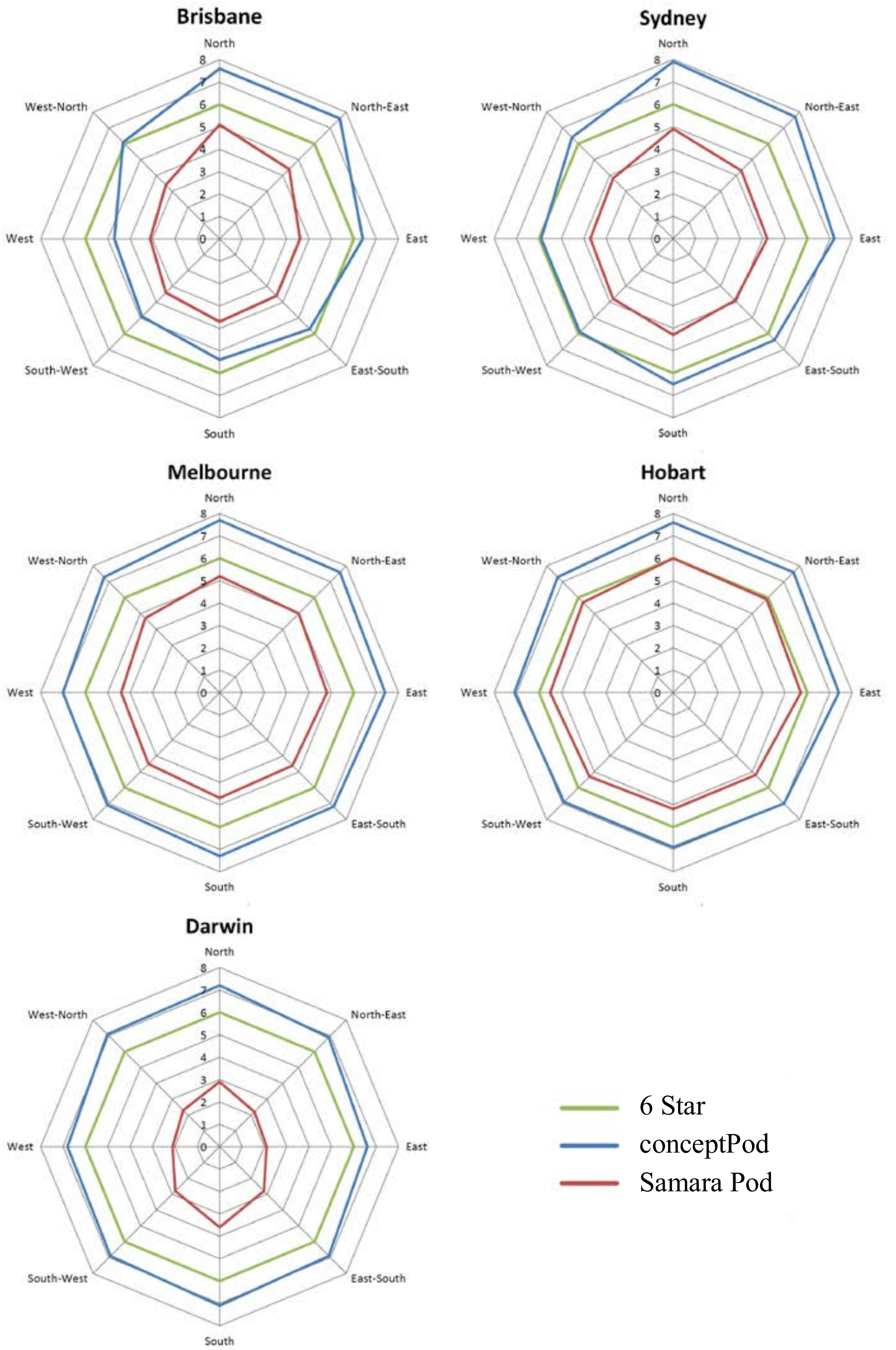

Figure 3 Orientation sensitivity analysis of Samara Pod and conceptPod

As evident in Figure-3 both the Samara Pod and the conceptPod perform very well in Hobart, although the conceptPod obtains minimum 1.5 stars more than Samara Pod across all orientations. It is worthwhile to note that, similar to Melbourne, the orientation of the Pods has less effect on the thermal performance, with only 0.8 stars and 0.7 stars of difference between the minimum and maximum rating for the Samara Pod and the conceptPod respectively. This may be due to the lesser effect of solar gain, optimised adaptive shading and highly insulated building fabric minimizing heat-loss from the Pods.

In Darwin the conceptPod performed reasonably well with performance varying between 6.6 stars as minimum on East and 7.2 stars as maximum on North (a difference of 0.6 stars). On the other hand, the base Samara Pod performed poorly, with a maximum rating of 3.6 stars when facing South, and a minimum rating of 2.1 stars for East and West orientations. This is a strong result showing the resilience and adaptability of the conceptPod design.

IMPROVED DESIGN AND ITS PERFORMANCE

All the lessons learnt from the optimization in each climate were applied to create a final design. The objective was to create a conceptPod that would work as best as possible in each climate. Even if the performance in some locations might be less than optimized, it could still have a good performance. This approach of standardisation, although counterintuitive and contrary to the notion of mass-customisation, was found to offer good manufacturing efficiencies for this particular manufacturer as it would require minimal changes in the Pod depending on the final location of the installation. In order to achieve this, further reviews of the effects of insulation levels and glazing types were carried out. It was found that two main insulation configuration (external wall/roof/floor) could be used in the Pod design depending on the location, for example, R = 4/4/2 for warm/hot climate such as Brisbane and Darwin, and R = 6/6/2 for mixed/colder climate such as Melbourne. Similar testing of glazing alternatives found that it was more effective to upgrade the main windows from double to triple glazing than to improve the insulation in the walls and roof from R4 to R6. It was also encouraging to find that the combination of triple glazing and insulation of R=6/6/2, resulted in ratings above 8 stars for Brisbane and Melbourne.

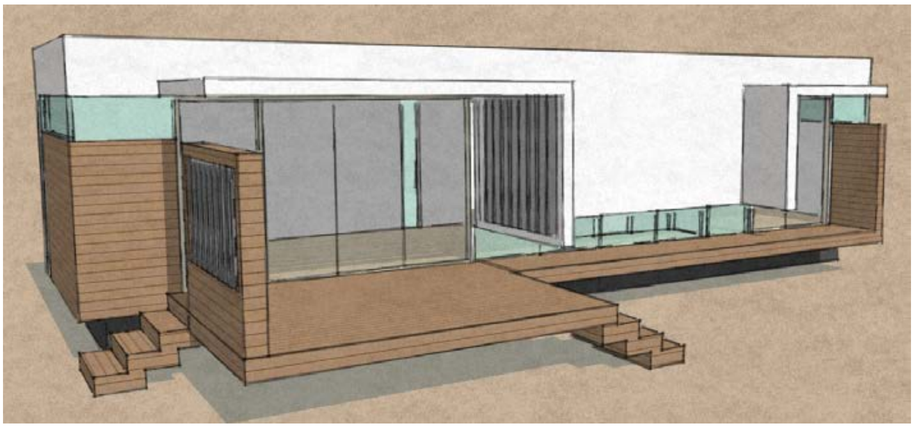

Figure 4 New integrated design of the conceptPod viewed from the North

The final conceptPod included carefully sized and located fenestrations with a mix of different types of high performance glazing. In combination with a mix of fixed and operable horizontal and vertical shading devices they simultaneously satisfied critical requirements of a good design – views, connection with the landscape, sense of spaciousness, privacy, aesthetics, and so on – and the essential aspects of a high thermal performance building – precise solar protection, passive solar heating, effective crossflow ventilation, and so on – to result in a truely integrated design.

A final set of simulations was carried out in order to assess the performance of the final conceptPod having insulation levels of R=4/4/2 and triple glazing in the main window as it was considered best option for balance between performance and cost. The simulations results are shown in Table-7. The only change in the Pod design between each location was the SHGC value of the glazing. The operable shades were designed to be easily adaptable to each climate without changing the overall design. The final results showed consistency with the earlier optimization exercise. The final conceptPod design performed well above regulatory requirements in all climates and achieved star rating up to 8.6 stars.

Table 7. Thermal Performance of Final conceptPod Design

Location	North (Stars)	East (Stars)	South (Stars)	West (Stars)	Comments
Brisbane	8.6	7.8	6.9	6.3	Glazing with SHGC = 0.3
Sydney	8.3	8.2	7.4	7.3	Glazing with SHGC = 0.3
Melbourne	7.7	7.5	7.4	7.1	Glazing with SHGC = 0.5
Hobart	8.2	8.1	7.7	7.9	Glazing with SHGC = 0.5
Darwin	6.7	6.2	6.7	6.3	Glazing with SHGC = 0.3

CONCLUSION

This study was designed to test several ideas and principles regarding the performance of the current Pod design and the limits of various strategies. The results of the final outcome show significant improvement in the thermal performance when compared to the existing design. More importantly, the combined engineering and architectural design research efforts produced an overall design that is easily adaptable for most of the climates and orientations studied. It is well-established that an optimized design for an individual climate and orientation would provide better result than a single “one size fits all” design. However, this particular optimisation process revealed that integrated design approach, with strategically embedded flexibility and economically rationalized redundancy in the type, amount and location of shading, glazing, and insulation, could result in a robust overall design outcome. This outcome – the conceptPod – showed remarkable resilience, for which the performance penalty from different locations and orientations was minimized significantly.

This research contributes to the debate on integrative design process and its significance for sustainable built environment in general; it also ascertains the path forward for a more comprehensive approach to net zero energy and self-reliant modular housing. The next phase of this research focuses on further integration of services and low carbon technologies to achieve this outcome. The lessons learned so far are being used to develope a next generation of ‘greenPod’, a prototype of which will be tested for a year to measure its actual performance and to compare with its predicted performance.

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Sustainable Habitat for Developing Societies: Learning from European Experiences

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ABSTRACT

The aim of sustainable development is a big challenge in the building sector. On one hand new technologies and materials are available, on the other hand life cycle assessment, including the energy performance and indoor air quality should be in line with green building standards. In many cases key players do not share common objectives for the project, may not understand how their work affects others.

Integrated design is thinking about how the parts fit together. But no matter what the scope of the project, structural design, heating, ventilation, air conditioning, lighting and wiring, and other key parts of the project are viewed as interrelated parts of the whole project. "Nearly Zero Energy Building" will be the standard for new buildings in Europe from beginning of 2020, due to the European Building Directive. Austria was one of the forerunners in eco building in the last twenty years. The measures and the experience how eco building, low energy and passive house standard disseminated in Austria are well documented and available.

The toolbox for integrated design contains experience with the most relevant elements: Starting with the establishment of clear project goals and quality management and ending with final inspection protocols, user information and maintenance. Certification systems for buildings aim to make sustainability transparent and provide a means of comparison. The paper proposes a similar concept for India, making the most of European experiences in building process and energy demand optimization and taking into consideration existing subsidies by the Government of India and evaluation procedures within the Green Buildings Rating System India.

Even though the climate is different, principles and products are basically same all over the world. After the discussion useful elements of the toolbox can be adapted to promote sustainable engineering and buildings.

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INTRODUCTION

Many of today's global problems arise from the availability and use of natural resources, caused by growing population and changes in lifestyle. The Ministry of New and Renewable Energy of India (Energy Access, 2012) states that India has the world's 5^{th} largest generation capacity and it is the 6th largest energy consumer accounting for 3.4% of global energy consumption.

In Europe the construction sector is in a change process, especially concerning the energy aspects. Buildings effect 40 % of total EU energy consumption and generate 36 % of greenhouse gases. To decarbonize the European economy reducing CO_2 emissions by at least 80 % and energy consumption by as much as 50 % by 2050 is necessary.

According to the EU Building Directive, European Parliament (2010), all member states have to ensure that by December 2020 all new buildings will be "Nearly Zero Energy Buildings". The various green successful schemes and initiatives undertaken by Austria will be discussed and understood. Austria is also a forerunner in eco building and passive houses.

INTENT AND OBJECTIVES

Need for sustainable habitats

Today, India is the second fastest growing economy in the world. In India, construction is the second largest economic activity after agriculture.

National Resources Defence Council and the Administrative Staff College of India have proposed a report on Strengthening the Indian Real Estate Market Through Codes and Incentives (2014) which clearly states: If all the states across India adopted the Energy Conservation Building Code (ECBC) and developers participated in strong programs for rating commercial buildings, an estimated 3,453 TWh of cumulative electricity could be saved by 2030, the equivalent of powering as many as 358 million Indian homes annually between 2014 and 2030 based on the current annual consumption level for electrified households. Additionally, 1,184 million tons of CO_2 emissions could be avoided by 2030. This underlines the need for sustainable habitats in India by creating a mass awareness and implementing stricter building standards.

Need for new policies and measures

According to IEA statistics report (2011), the electricity consumption in India has nearly doubled from 407.48 TWh in 2000 to 835.40 TWh in 2011 and the CO_2 emissions have risen drastically from 972.13 Mt of CO_2 to 1745.06 Mt of CO_2. From these figures we can infer the higher are the electricity consumption, higher is the CO_2 emissions. Though India has a number of policy initiatives to mainstream energy efficiency and green buildings as control and regulatory instruments, including appliance standards, mandatory labelling and certification, energy efficiency obligations, and utility DSM (Demand Side Management) programs; economic and market-based instruments; fiscal instruments and incentives; support, information and voluntary action, there is definitely a strong need for better solutions to create a wider impact to achieve low carbon economy in the coming years.

Integrated Design

Integrated Design is advisable in managing the complex issues arising from planning buildings with high environmental and social ambitions. Key issues are collaboration in multi-disciplinary teams,

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discussion and evaluation of multiple design concepts as well as clear goal setting and systematic monitoring. In the early design phases, the opportunities to positively influence building performance are great, while cost and disruptions associated with design changes are comparatively small.

The Integrated Design Approach will result in better energy performance, reduced environmental problems, optimized indoor climate, lower running costs, reduction of risks and construction defects, user acceptance and higher process quality concerning timelines, construction cost, quality of work delivered.

EXISTING POLICIES AND MEASURES IN EUROPE

Case study Austria

Austria is a European country with a comparable high share of Nearly Zero Energy Buildings and was one of the forerunners in eco building in the last twenty years. This development was enabled by a sample of instruments:

Building Codes: The building codes are adapted step by step towards the "Nearly Zero Energy Standard" to implement the European Building Directive on national level. The National Plan OIB, (2011) specifies the limits for heat energy demand, primary energy and CO_2 for new buildings and also in case of renovation.

Subsidies: In Austria subsidies for building or renovation are available if specified building standards e.g. heat energy demand, are documented in the obligatory energy passport. In general the energy performance must be better than the building code requirement. The City of Vienna evaluates social housing building projects by an interdisciplinary jury and launches competitions for sustainable building. The subsidy for a solar thermal plant with a solar fraction of the heating energy demand (for heating and hot water) of at least 30 percent is 25 percent of the eligible investment costs.

Government initiative for public buildings: For public buildings, the governments of the provinces take the responsibility as a trend-setter in green public procurement; specific criteria were developed by consultants in tight cooperation with the administration. The Planners Guideline Planungsleitfaden Vorarlberg (Fechner, Haas, 2010) is a crucial tool for the implementation to be practiced.

National Programs: Programs are the third pillar beside the legal and economic instruments for climate policy. The Austrian Program on Technologies for Sustainable Development "Building of Tomorrow" initiated innovation in sustainable buildings like Passive House demonstration projects, development of building concepts and components, social studies. The Program "Factory of Tomorrow" addresses the trade and industry as well as service enterprises to focus on zero-waste and zero-emission technologies and methods of production, increased use of renewable raw materials for materials and products, development of new partnerships and co-operations as well as in-house models for further training and participation of employees in order to achieve these objectives

Klimaaktiv is embedded in the Austrian federal climate strategy, consisting of a bundle of measures of regulation, taxes, and subsidies. Klimaaktiv has gathered all voluntary and supportive measures under one umbrella in the four thematic clusters construction, energy efficiency, mobility and renewable energy. The climate protection program goes into partnerships to realize climate friendly building.

The core objectives of klimaaktiv are:

1. Training for professionals: the European BUILD UP Skills initiative launched national stakeholder platforms to develop roadmaps for vocational training concepts in the construction sector. By this the needed skills to realize the Building Directive shall be built up. klimaaktiv supports and provides qualification and coordinates training and vocational education in various fields.

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2. Setting standards and safeguarding quality by introducing quality standards for products and services and by establishing quality management systems, e.g. for biomass district heating systems or for buildings. This is important, because young and booming markets often cannot provide sufficient quality.

3.Providing information and advice, raising awareness; klimaaktiv mainly focuses on offering consulting to companies interested in making their production processes energy efficient, or renovating their facilities, or introducing mobility management, or changing over to energy efficient appliances and IT systems. klimaaktiv provides support for consultants by equipping them with new tools, by benchmarking energy efficiency and by offering further training on specific issues.

4. Activating and networking partners; successful climate protection depends on the commitment of existing initiatives and networks as well as on that of the business and the public sector. klimaaktiv aims at bringing these players together and at creating a powerful network for climate protection.

Figure 1: This Logo is used by partners of the initiative to express the engagement in climate protection

Building standards: In Austria several certification schemes are in use to label buildings:

* **EU Green Building:** compared to other systems this standard is not covering many aspects of sustainable building

* **klimaaktiv building standards:** for new and renovated buildings, free available on www.klimaaktiv.at , with reference to passive house standards

* **OGNB**, Austrian Sustainable Building Council (including klimaaktiv criteria)

* **BREEAM,** Building Research Establishment Environmental Assessment Methodology

* **ÖGNI,** Austrian Association for Sustainable Real Estate Management (ÖGNI), Germany's DGNB.

The use of building standards is required for public buildings or for funding occasionally

Consultancy: Energy advising is very common in Austria to raise the awareness and to help to make best use of subsidies. Consultants are organized in networks by the provinces. The service is offered free or to a low price, sometimes it is part of the subsidy.

Tools for planners: Sustainable Buildings require new competences in management of integrated planning processes. Starting with the establishment of clear project goals and quality management and ending with final inspection protocols, user information and maintenance. As an example, the series "Quality line" for the optimized integration of solar heat, heat pumps, HVAC, is provided by the klimaaktiv initiative, (Fechner, J., 2012) Qualitaetslinien Haustechnik.

Table 1. Quality Line in the Construction Process

Step	Tool of Quality Line
1. Basic Decisions	Information for Purchaser, Checklist
2. Call for Tender/Cost Estimate	Specifications for Tender
3. Selection of Tender, Contract	Criteria
4. Quality control	Inspection Protocols

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For the selection of energy efficient electric appliances a consumer friendly database is run by klimaaktiv, presented on www.topprodukte.at. Professionals find here the most efficient pumps, boilers and many other components, end-user are most interested in energy demand, investment and running costs of household appliances.

WHICH OF THE PRESENTED STRATEGIES AND MEASURES CAN BE REGARDED AS USEFUL FOR SUSTAINABLE BUILDINGS?

- Sustainable building must be defined in the context of the country, its climate, culture and society. Sustainable concepts have to unite ecological, social and economic requirement, they are always the result of discussion, valuation and negotiation. Exchange of experience and learning from each other is urgent to solve problems on global level.
- Certification schemes provide information and criteria for sustainable buildings. Depending on the origin of the scheme the criteria are based on the understanding of the creator and his system.
- A Sustainable Building Strategy is the basis for a coordinated and effective development of the building sector. The EU Building Directive is an efficient policy strategy, but it covers only the use of energy. Other aspects of sustainability need to be met.
- National programs for sustainable buildings are triggering innovation and good practice support the market transformation. As soon as sustainable solutions are available, legal and economic measures (e.g. subsidy schemes) are necessary to implement such a strategy. Quality management is crucial, it is the responsibility of the investor and user to define sustainable quality and proof, as the legal requirements and the administration only regulate some aspects.
- National initiatives like klimaaktiv are bundling measures to reach grassroots level. If the government introduces such a scheme, it is available nationwide for free.

Seven steps can be identified as core elements referring to existing practice in Europe and India, the authors propose to implement and coordinate these measures within a national initiative:

1. Analysis of building practice incl. energy performance, poor quality and damages (first part of SWOT analysis). In cooperation with Universities such research can be a field of learning and many researchers can be involved.
2. An innovation program for sustainable building produces the options for the future, involving Universities and the building industry.
3. Building standards for all relevant kind of buildings incl. domestic buildings (e.g. klimaaktiv building standards in Austria or in Switzerland MINERGIE)
4. Analysis of stakeholders and actors (to learn about their need for capacity building) and definition of learning targets.
5. Development of a vocational training scheme for sustainable building incl. certification (e.g. ISO 17024). Trainings can be offered by educational institutions, based on contracts.
6. Networking and partnership. Persons who absolved special trainings are invited to join the network of sustainable building professionals
7. Evaluation of trainings, refining trainings.

An evaluation of Austrian tools towards adaptation to India could be made; Energy Consulting for investors and for users could be mentioned; universities could engage in a targeted exchange of academic staff and students to learn from each other.

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OUTCOMES: RECOMMENDATIONS FOR SUSTAINABLE HABITATS IN INDIA

A program "Sustainable Building for India", implementing the discussed strategies and measures can make sustainable habitats a greater success in India.

- Awareness raising should start with presentation of good practice, e.g. an award for sustainable buildings(http://www.klimaaktiv.at/bauensanieren/staatspreis.htmlor http://iet.jrc.ec.europa.eu/energyefficiency/greenbuilding) .
- Besides (more or less expensive) certification schemes additional incentives should be developed. The above mentioned strategies and measures can be used but must be adapted, as India has different climatic conditions; the architecture of the building varies from region to region.
- The Government of India can encourage industries; especially SME's to come up with new green materials at affordable cost so that the end user can implement the green idea into reality.
- In India, Excise Duty is imposed on every product that is manufactured in factories. The Government should intervene by reducing the service tax and other taxes imposed on products manufactured by Certified Green Factories to encourage green practices.
- The Government of India can introduce subsidy schemes either nationwide or state wide for green building practices to encourage active participation by the public.
- To encourage Sustainable Building and also to increase the share of renewable energy, an increase of the budgetary allocation by the Government of India is necessary.
- The Government of India can enforce a strict regulation all over the country to increase the share of renewables from the existing 1% to 10% like the EU Building Directive.
- Construction workers should be trained to understand the various green building practices throughout the construction period. Before the Project work has begun, the contract should have a mandatory agreement that trainings in green building practices have to be undertaken by supervisors, clients at different stages of the project to understand the purpose.
- When constructing a new building, license from EIA has to be obtained. Renewable practices must be stressed and included in the license procedure
- When the customer approaches bank for loans for green residential or commercial projects usually environmental approvals are requested for the financial closure but no such requirements regarding energy approvals.

TOOLBOX FOR INTEGRATED DESIGN FROM AUSTRIAN INITIATIVE ' KLIMAAKTIV'

Klimaaktiv provides tools for effective Integrated Design for Sustainable Buildings in Austria. These tools are available for free and have great potential to be used as powerful tools for Indian habitats. Guidelines for optimized integration of photovoltaic, solar heat, HVAC and electric appliances, air quality are given. Klimaaktiv would also help in the transfer of knowledge for India to make integrated design reachable to all. The various Tools are listed below.

1. Photovoltaic calculator is an efficient tool (xls tool) for the rapid assessment of efficiency of photovoltaic systems for new construction and renovation buildings. It is available in the web link (http://www.klimaaktiv.at/tools/erneuerbare/pv_rechner.html)

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2. Solar heat: Guidelines for counselling, call for tender, acceptance protocol are given for systems for residential buildings for heating water, with or without integration in the heating system. (http://www.klimaaktiv.at/publikationen/bauen-sanieren/qualitaetslinien/solarwaerme.html)
3. HVAC:
   Guideline for counselling, call for tender, acceptance protocol (http://www.klimaaktiv.at/publikationen/bauen-sanieren/qualitaetslinien/komfortlueftung.html)
4. Heat Pumps :
   Guidelines for counselling, call for tender, acceptance protocol buildings for compact devices (http://www.klimaaktiv.at/publikationen/bauensanieren/qualitaetslinien/komfortlueftung.html) and to find the right heat pump heating , JAZcalc derives the seasonal performance factor under standard conditions for a quality geothermal community
   (http://www.klimaaktiv.at/tools/erneuerbare/JAZcalc.html)
5. Indoor Air Quality : criteria in klimaaktiv
   - HVAC (http://www.baubook.at/kahkp/?URL_R=http%3A%2F%2Fwww.baubook.at%2Fm%2FPHP%2FKat.php%3FSKK%3D1761.13213.13214.13255.13257.13243%26SW%3D8%26ST%3D12&SW=8)
   - Selection of building products (low emission) (www.baubook.at)
   - Qualitycontrol(http://www.baubook.at/m/PHP/Kat.php?SKK=1761.13213.13214.13255.13257.13245&SW=8&ST=12)
6. Environment data: baubook.at also provides data for Global Warming Potential, Acidification Potential and Primary Energy (grey energy)
   (http://www.baubook.at/m/PHP/Baum2.php?ST=44&SW=8&auto_right_frame=y)
7. In order to make the quality of a building measurable and comparable, the climate-active building standard was developed.
   (http://www.klimaaktiv.at/bauen-sanieren/gebaeudedeklaration.html) and in English (http://www.klimaaktiv.at/english/buildings/Buildings.html)
8. There are various Labels: e.g. solar key mark for solar thermal (http://www.estif.org/solarkeymarknew/) or EHPA for heat pumps (http://www.ehpa.org/). It is easy to handle quality labelled products.

CONCLUSION

Even though the climate is different in Austria and India, many principles and in the meantime also many products are basically the same all over the world. Useful elements of the presented toolbox can be adapted to promote sustainable engineering and building.

The leading engineering schools can initiate innovation for sustainable building, facilitating hands-on “real life” education and continuous exchange with industry on new technologies, materials and process design. Such an educational model focusses on the student’s role as active “innovation broker” between his employing company and the teaching and research staff at the university. Austria can contribute and bring in examples for innovative and successful didactic and organizational elements and their actual benefit for regional enterprises.

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Full scale dynamic monitoring: school and office in Aosta, Italy.

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ABSTRACT

Full scale buildings sometimes are too big to be fully monitored and, moreover, if occupancy are inside, they can fail some measurements. FINAOSTA (Finanziaria Regionale della Valle d'Aosta/ Regional Holding Company of the Aosta Valley) is a research activity conducted by University of Florence on two buildings – one school and one office building- located in North Italy, Aosta. Buildings have different age, different exposition, different material construction. Aim of the research is to propose an appropriate methodology to monitor thermal plant and to investigate on technical solutions for reducing energy consumptions in both buildings. Two different plant system solutions are identified and buildings are monitored through an electronic system regulated from an internet platform; data collected are used to evaluate energy saving and indoor comfort due to both technical solutions. Due to the high volume of the building, a decision has been made on portions to be monitored and compared: results are used as input to simulate the full scale buildings. The paper will evidence difficulties in defining zones to be monitored and obstacles due to the inappropriate intervention of occupants on the instrumentation.

INTRODUCTION

This research focused on problems in monitoring and simulating full scale building with high volume as school or offices, and to compare different technical solutions adopted for the heating and cooling plants.

Very often monitoring results can be unreliable and the parameters to be monitored are difficult to predict or to model depending on the accuracy of the simulating model level. A common practice is to use energy simulation tools to verify monitoring results: in this research activity energy simulation has been used to extend investigation on monitored parameters and energy requirements due to application of different technical solutions on full scale building, so the main difficulty was the right scale model in ESP-r [1] (the energy tool used for energy dynamic simulations) to achieve the objectives of research. In addition, during all the research stages, many problems was related to uncertainty of results due to human factor for two reasons: In monitoring activities, users actions interfering with the right functioning of monitoring equipments, making difficult to interpret results and to compare monitoring data in different rooms. In energy simulation activities it was impossible to translate users behavior and to describe active control plants by occupants through operational control law with a dynamic simulation tools. This type of problem suggests the necessity to develop new strategies and methodologies to analyse the state-of -art in full scale dynamic monitoring and energy simulation.

OBJECTIVES

The main objective of FINAOSTA research activity is to verify the energy saving and the convenience due to one of the technological solutions for plants compared to the others. As explained, an utility in using building energy simulation is to simulate the impact of each technological solution for plants on full scale building even if, in reality, technical solutions has been applied only on portions of buildings. In this work, the investigations carried out on the office building and the school started to verify: the energy required for each building considering the application of the heating and cooling system control devices and the energy consumption; the indoor comfort of occupants in workplaces.

Therefore starting from a known of the building total consumptions and using monitoring results to simulate full scale building, it is possible to define the reasons of occupants discomfort and to evaluate the buildings energy requirements considering internal gains during the simulation period. Finally, comparing different plant system solutions introduced into the buildings during the monitoring period it estimated the economic costs during plants operation periods. It was possible to propose and to evaluate the impact of technological solutions adopted for the plants and for the building skin, and how these aspects can reduce the energy consumption and the comfort level of occupants.

DESCRIPTION OF BUILDINGS

The Department for Productive Activities of Aosta (Fig.1) was built in 1939 and actually consists of two building blocks: the earliest building with a mansory structure, brick external wall 70 cm thick and concretebrick floors, thermal plant has a heating functioning only with radiators; a new block to the West, built around 1980-1990 with a reinforced concrete structure, brick external wall 35 cm thick at the ground floor and a double glazing facade at the first and second floor; thermal plant with fan coil has a heating/cooling functioning [2] .


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The Manzetti School (Fig.2)was built in 1958 and consists of four storey in which there are classrooms, laboratories, and administration offices and a basement for deposits and archives. The building has a concrete structure with brick external walls 50.00 cm thick with a natural stone cladding on the fronts along public road and plaster on the fronts along intern court, concrete-brick floors, floors in brick and pitched roof with ceiling tile and the concrete slab finish in terracotta tiles. The school is served by a thermal plant for the winter heating only with radiators [3].

THE ENERGY ANALYSIS PROGRAM

The purpose of energy analysis is the identification of technological and innovative/non-invasive solutions to optimize the heating/cooling plant systems and the comfort indoor in workplaces.

The operational phases preliminary to monitoring activity:

1. Identifying groups of representative rooms in both buildings for the monitoring. Three groups were identified, differing for exposure, construction elements for facades, thermo-hygrometric conditions, and type of plants. Each

group consists in three rooms: Room 1; Room 2 and Room 3;

2. Monitoring of thermo-hygrometric parameters into the rooms and analysing technological systems and construction typology of facades, windows and doors transmittance, heat capacity, thermal inertia, etc.

This first analysis performs a first setting of the REMOTE MANAGEMENT SYSTEM (monitoring, control and regulation) as an innovative technology solution.

Fig. 2. Manzetti School building. (a) South front with natural stone cladding; (b) East front with plaster cladding.

Methodology and parameters of the Energy analysis

For each building it has been chosen a "thermal zone monitoring", consisting of groups of three rooms with the same use and exposure. The groups has been studied, investigated and monitored by installing tiny-tags for the measurement of dry bulb Temperature (dbT) and relative Humidity (RH). The accuracy of instruments is ±0.5°C at 25°C for dbT and ±3.0% at 25°C for RH.

These parameters have been recorded and compared to the graphs concerning the ambient temperature and humidity measured by outdoor tiny-tags. This allowed to analyse the dynamic behaviour of buildings related to the external climatic conditions and to control the heating/cooling system operation.

The following indoor parameters have been monitored for each room:

- dry bulb temperature in the volume occupied by people (about 1.60 m above the floor);
- dry bulb temperature near the ceiling (about 20 cm below the ceiling);
- relative humidity in the volume occupied by people (about 1.60 m above the floor);
- thermal energy provided by each radiator/fan-coil.

The outdoor parameters monitored are:

- outdoor dry bulb temperature;
- outdoor relative humidity.

Indoor temperature and humidity in the room air volume represent two parameters to verify and optimize indoor comfort levels (occupants well-being). Temperature near the ceiling has been monitored to calculate the thermal gradient into the room during winter season and the energy consumption to maintain a comfort temperature in the volume occupied by people. In order to optimize the heat from plant elements and to reduce the phenomenon of stratification, the remote management system (monitoring, control and regulation) controlled the heating units.

Three different technical solutions were adopted in school Manzetti monitoring activity: for each room of a representative group has been installed heat accounting system to estimate energy consumption and has been indicated indoor/outdoor monitored parameters.

Room 1 represented the active control considering the installation of a technological solution motorized threeway valve connected to an electronic control unit modulating the input flow of fluid into the heating plant element; an occupancy detector activated by control unit manages thermal plant and lighting. In Room 2 it has been installed a thermostatic valve to control set point temperature. Finally the Room 3 represents the base case devoid of a system of thermoregulation.

Technical solutions adopted in the Department for Productive Activities during monitoring activity concerns only two cases: the base case and the active control.

The groups monitoring protocol included summer season and winter season. The electronic management system proposed as innovative technological solution acting on:• remote management of plant elements; • energy delivered by terminals of system plant ;• thermohygrometric parameters in the rooms.

Collecting and recording data system is realized by an electronic platform: the monitoring equipments (sensors and actuators, plant controls etc) are connected to a local control unit located near radiator/fan coil. The local unit communicates with a central unit through the local area network.

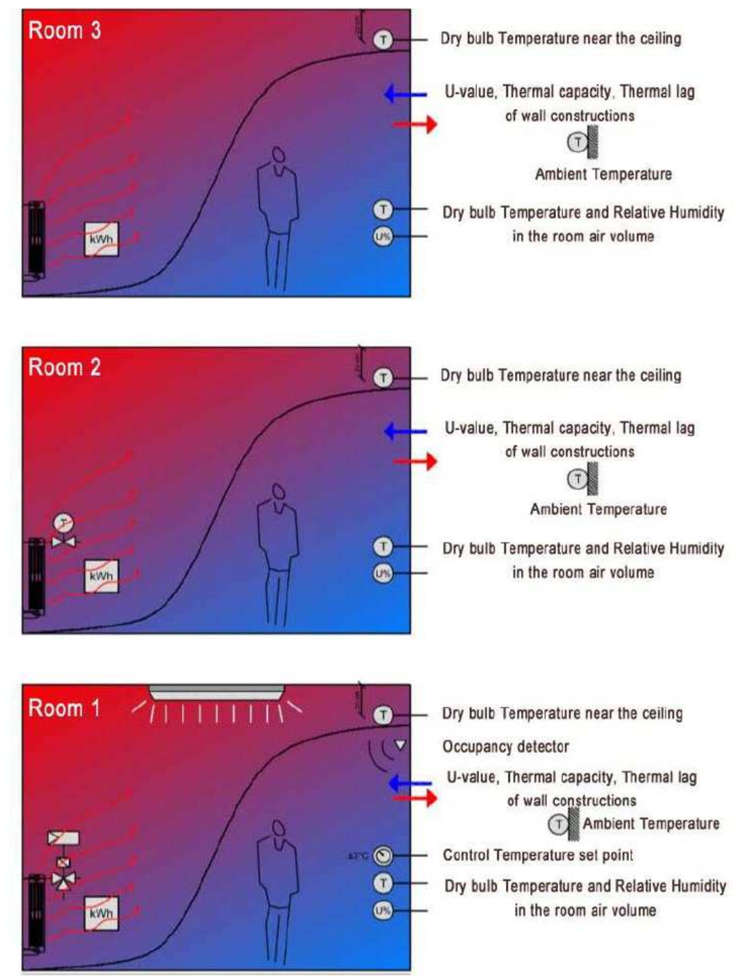


Fig. 3. Technical solutions adopted in school Manzetti monitoring activity for each monitored room. In the picture the curve represents the trend of the temperature inside the room.

Fig. 4. Installation of motorized three-way valve connected to an electronic control unit on radiators (a), on fan coil (b).

Energy analysis results

Dynamic simulation was used to achieve the research objectives supporting monitoring activity by solving many problems due to the uncertainty of monitoring results. During the monitoring activity, the actions of the occupants interfered with the functioning of monitoring equipment, making it difficult to interpret output data.

In the Department for Productive Activities of Aosta, comparing the case base with the new technological solution for thermal plant, monitoring results revealed that the active control produced a real energy saving in terms of economic resources (for example, in the rooms without active control, thermal plant was never switched off during weekends), but it does not solve problems connected with indoor discomfort in workplaces. During winter period in the rooms with North exposure dbT is below the range value for indoor comfort because of the building massive envelope without insulation, with a transmittance equal to 0.85 W/m²K (value above the minimum required by law). Instead rooms of block 2, with a East and West exposure, in addition to high internal gains, benefits of free solar gains thanks to the double glazing facade: monitoring data show the habit of users to manually turn off fan coil because dbT exceeds 30°C throughout all the working period. For the same reason, during summer period fan coil never switched off because of the high temperature due to internal gains and solar gains, especially in rooms with West exposure. About relative humidity, it must be specified that the new building does not have a natural ventilation system and the monitored data shows RH value less than 20-25% with an increase in the perception of discomfort (dry air) during coldest weeks.

MODELLING STRATEGY

As a consequence of the difficulties evidenced in interpreting monitored results, it was necessary use dynamic energy simulations to investigate energy demand expanding survey on full scale building. The input for the energy simulation starts from the description of both buildings as complex systems considering all the environmental and technological aspects in a specific climate: weather data represent the boundary conditions. The analysis approach used in the construction of the buildings analysis models involves the following steps: 1. Identification of building blocks; 2. Analysis of rooms uses; 3. Definition of thermal zones. By definition, an analysis model is a simplified representation of reality: in both cases, it is adopted an approach to the model construction starting from the general to the particular. First was carried out the analysis of construction typology of each building, making possible a division of different blocks each one characterized by structure typology, construction of facade elements, type of heating/cooling plants.

By focusing on each building block, it has been conducted an analysis on room occupancy on each floor: understanding activities taking place within the rooms of a building as a school or a public office is essential for a correct identification of internal gains because they are related to the number of occupants inside the room, the equipments (number of terminals, printers, etc.), type and number of light sources. This analysis is aimed at the subsequent identification of "macro-zones", entities with specific thermophysical characteristics representing thermal zones in the ESP-r model.

In the case of the Department for Productive Activities of Aosta, as a result of a first analysis of exposure, orientation and construction specifications of the building complex, it has been reasonable to divide the building in three blocks for different construction type, thermophysical features of facades, and plants typology (Fig. 5). Since the block 3 is similar to the block 1 for construction typology, thermophysical characteristics of the facades and nalysis

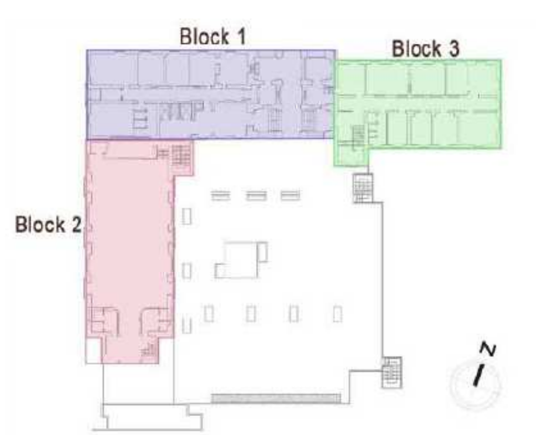


Fig. 5. Plant of the blocks identified in Department for Productive Activities of Aosta.

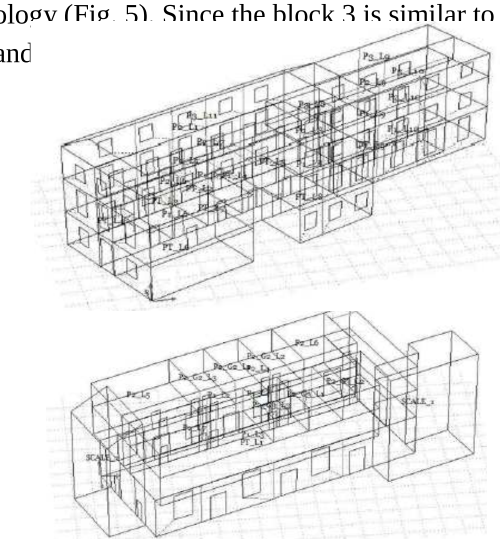


Fig. 6. Esp-r models: Block 1 South view (a), Block 2 East view (b).

consists only in blocks 1 and 2. Each block was divided into a thermal zones, each zone can identify one or more rooms into the building that are characterized by a defined volume of air at the same temperature, with the same construction materials and the same internal gains. A single thermal zone can include rooms with similar aspects: the "similarity" is to be found in exposure, orientation, intended use, housing characteristics, typology of plants.

Therefore, zones conditions are strongly affected by the internal gains connected to the activities/uses of the rooms so, as a base for the analysis model in ESP-r, it was built a volume model indentifying each zone for different intended uses of office rooms [4]. Consequently to the identification of two different blocks it has been created two analysis model, one for each block (Fig. 6). More specifically, for the group of rooms interested by the energy monitoring program, it was decided to represent each room as a single thermal zone in order to be able to compare directly the output data provided by the simulation in ESP-r and the parameters recorded during monitoring. The same methodology has been applied to the Manzetti School, where the planimetry configuration has suggested the identification of two blocks with an L form, similar for orientation, conFiguration, structural typology, and type of plants.

SIMULATIONS

As case of study for the dynamic simulation it is represented the model analysis of the Department for Productive Activities of Aosta.Two different conFiguration files has been created for each block identified in the building complex:

- Block1_base case, consisting of four floors with wall structure with actual heating plant with radiators. No occupancy.
- Block1_upgrade project, the same of the base case considering technological solution for heating plant and occupancy.
- Block2_base case, consisting of three floors with concrete structure and double glazing system for facades at first and second floors. Actual heating/cooling plants with fan-coil.
- Block2_upgrade project, the same of the base case considering technological solution for heating/cooling plant and occupancy.

For assessment purposes, it has been considered several assumptions: reference weather data, construction elements for facades, occupancy and operational schedules, control files of the heating/cooling plants system.

To implement occupant behaviour into the model simulation it has been considered operational schedules to represent windows openings and infiltration by imposing different rate for the ventilation (Air change per hour) based on daily profiles for heating and cooling period.

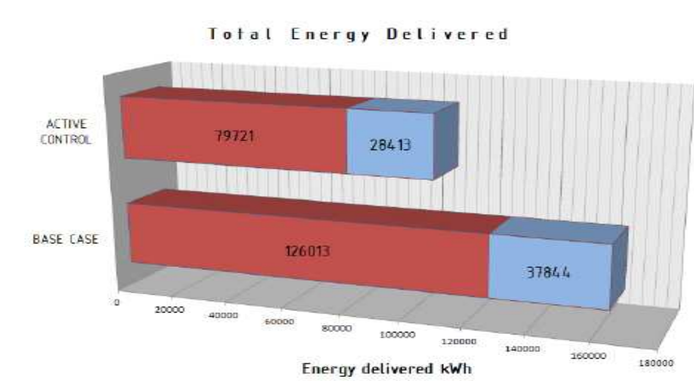
RESULTS OF ENERGY SIMULATION

The results of dynamic simulation carried out on the Department for Productive Activities focused on two aspects:

• Total energy delivered, the thermal energy required for each building considering the application of the heating and cooling system control devices and the energy consumption [5] ;

• Indoor comfort of occupants in workplaces.

Simulating results, according with monitoring results, revealed that the active control produced a real energy saving. During winter period (15 October-15 April) and during summer period (1 June - 15 September) in the base case total energy delivered is 163857 kWh; considering the introduction of an active control on thermal plants, total energy delivered in 108134 kWh, obtaining an energy saving of 34.2%. (Fig. 7).



control.

Thermo hygrometric conditions: Winter Period

To investigate thermohygrometric conditions of the representative rooms with different exposure in the simulating model (the same rooms selected for the monitoring activity), it has been compared dry bulb temperature, relative humidity and zone resultant temperature to show the difference between the base case and the active control (data refers to a tipycal week in winter period). (Fig.8)

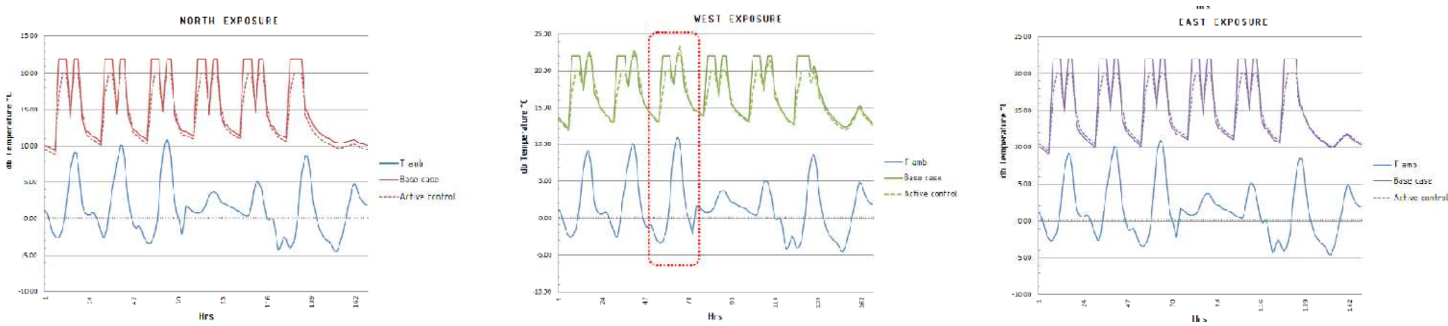


Fig. 8. Zone dry bulb Temperature comparing base case and active control in rooms with different exposure

During the winter period, when radiators/fan coil are switched off, db temperature is affected by the trend of ambient temperature. During the nigth and the weekends db T decreases significantly because of athe heat losses through the external wall. Thermohygrometric conditions of the room with a West exposure are better than the other rooms thanks to the contribution due to the direct solar radiation trought the double glazing facades; dbT with active control often exceeds T setpoint because it has been considered internal gains.

Relative humidity is the more significant parameter to describe thermo hygrometric comfort of zone in which people leave and work, and it depending on the extent of internal gains within the zone. Assuming occupants to be sit and working into office room , relative humidity values have to be 40-60% corresponding an intern dry bulb temperature of 20-22°C. Considering the simulating model used to establish energy saving due to a specific tecnological solution on thermal plant, the simplifying assumptions made on occupancy in the base case do not allow to compare RH values between base case model (no internal gains) and active control model (considering occupants and equipments). RH results are shown in Table 1a.

The zone resultant temperature of a room, T Res, is a useful parameter to describe indoor comfort and it represents the average between the dry bulb internal temperature and the mean radiant temperature of the walls in a zone. T Res values are shown in Table 1b. T Res values are always lower than comfort range values. Only in the case of west exposure, in the early hours of the afternoon, T Res reaches 21-22 °C when the internal surface temperature of the double glazing facades increases thanks to the direct solar radiation.

Table1. (a) Relative Humidity and (b) Zone Resultant Temperature comparing base case and active control in rooms with different exposures. * RH m and TRes m represent the mean value calculated on a period limited to the working hours.

Relative Humidity						
	Base case			Active control		
	RH max (%)	RH min (%)	RH sq (%)	RH max (%)	RH min (%)	RH sq (%)
North exposure	52	16	22	55	19	35
West exposure	43	16	20	44	18	26
East Exposure	49	16	21	49	16	29

Zone Resultant Temperature						
	Base case			Active control		
	TRes Max °C	**TRes Min °C**	**TRes sq °C**	**TRes Max °C**	**TRes Min °C**	**TRes sq °C**
North exposure	18.8	10.0	17.3	17.3	9.5	15.9
West exposure	21.8	12.8	19.5	22.3	12.5	18.6
East Exposure	19.3	9.6	17.4	18.0	10.0	16.5

In general, thermo hygrometric conditions of room with West exposure are better than the other rooms with different exposure thanks to the direct solar radiation trough the double glazing facades. Internal surface temperature of the double glazing facades with West exposure is significantly affected by the trend of direct solar radiation graph .

The internal surface temperature values for the other exposures are lower than the previous case: in particular, in room with North exposure internal surface temperature is almost constant because of the lower thermal capacity of the non insulated external wall and it does not exceed 14 ° C contributing significantly to the decreasing of the operating temperature within the room.

Thermo hygrometric conditions: Summer Period

During summer period it has been considered rooms with East and West exposure because the room with North exposure, located in the Block 1, is provided of radiators for the winter heating only.

According with monitoring output data, in the base case it was assumed that fan coils never switched off during the weekend, so the difference between base case and active control is more evident during the weekend when db T is free to float producing rooms overheating. (Fig. 9)

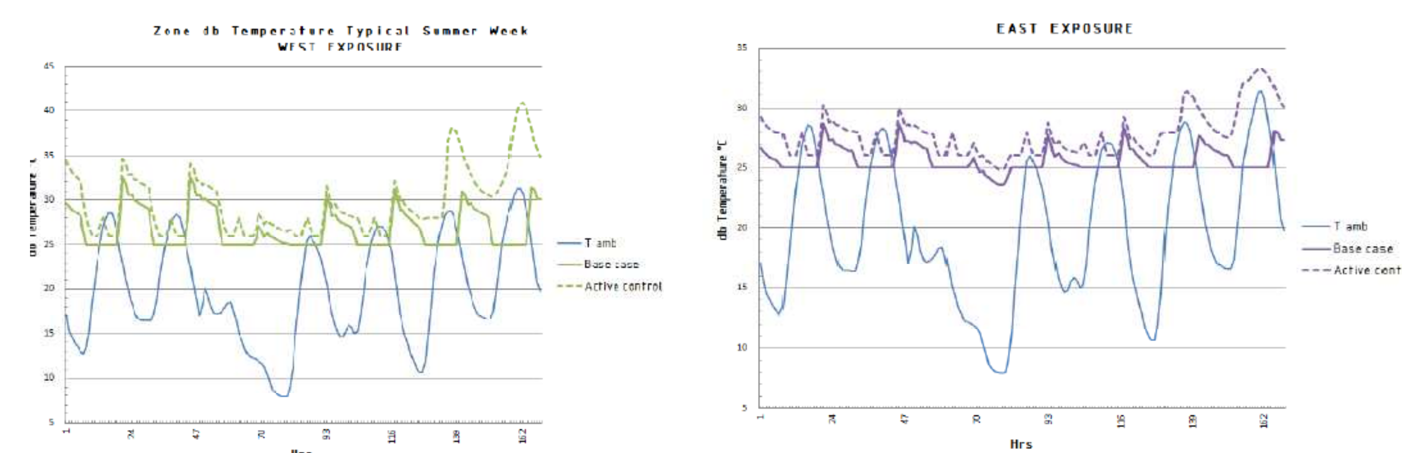


Fig. 9. Zone dry bulb Temperature comparing base case and active control in rooms with different exposures

During the morning, dbT increases over 30°C when fan coil switched off. In relation to the problem of summer overheating, the addition of a shading system has a positive effect to reduction of the temperature of to indoor surface of the double glazing façade with the aim to prevent the direct solar radiation to penetrate inside the rooms. Even if this solution produces an improvement of indoor comfort bringing intern dry bulb Temperature values closer to the comfort range during working hours, there is a large gap between inside and outside temperature.

As a second hypothesis, it has been studied the effects of night cooling on indoor thermo hygrometric conditions. It was used a detailed geometric model of a room considering active control solution and the worst conditions of exposure (West exposure). The room has been divided into two thermal zones, where the zone_1 represents the volume portion of the false ceiling (Fig. 10a); two ventilation opening grids have been introduced at the top and at the bottom of the room and it was created an airflows network [6] with a scheduled control (Fig.10b).

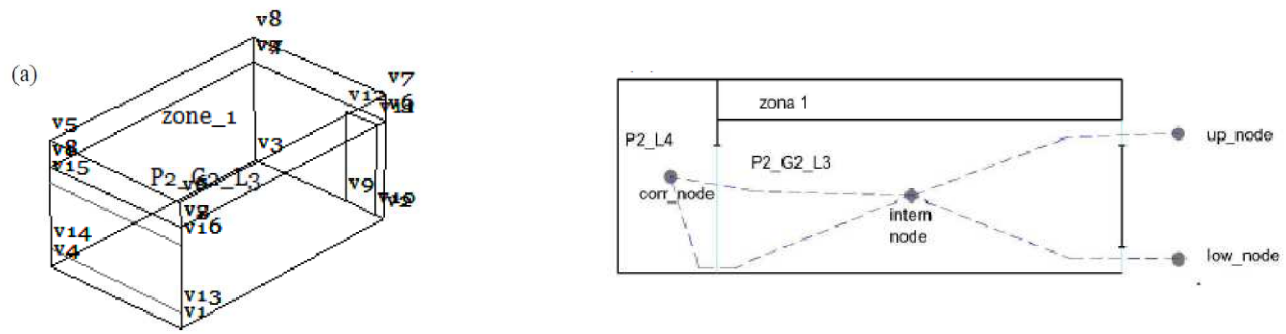


Fig. 10. a) ESP-r model of room with West exposure adding ventilation grids; (b) Airflows network diagram to represent natural ventilation in the room

It was performed a simulation of db T comparing three different strategies to solve summer overheating:

- Active control, considering the cooling plant only;
- Shading system, introducing a shading system to the windows to protect the room from direct solar radiation;
- Airflow network, considering all previous strategies and natural ventilation (night cooling).

Db Temperature decreases significantly thanks to the addiction of a shading system to the transparent facades. The addiction of a natural ventilation system does not have a significant improvement on thermo hygrometric conditions within the room: the gap between Zone db Temperature and Ambient Temperature in still high during the night (Fig. 11a). About Zone Relative Humidity, natural ventilation maintaining RH value within the comfort band (40-60%).

Stronger airflow will be induced when there is a large vertical distance between inlets and outlets openings, and when there is a large difference between indoor and outdoor temperatures.

In this case natural ventilation was not sufficient to activate an airflows convection in the room because of the small distance between opening grids placed at the top and at the bottom of the room. Moreover, the west front is also not directly exposed to the night breezes, infact the main wind direction in July and August is South-North. For these reasons the only good solution to improve the indoor comfort in the rooms of the block 2 is the use of external solar shading on the double glazing facade or a new technological solution for the facade.

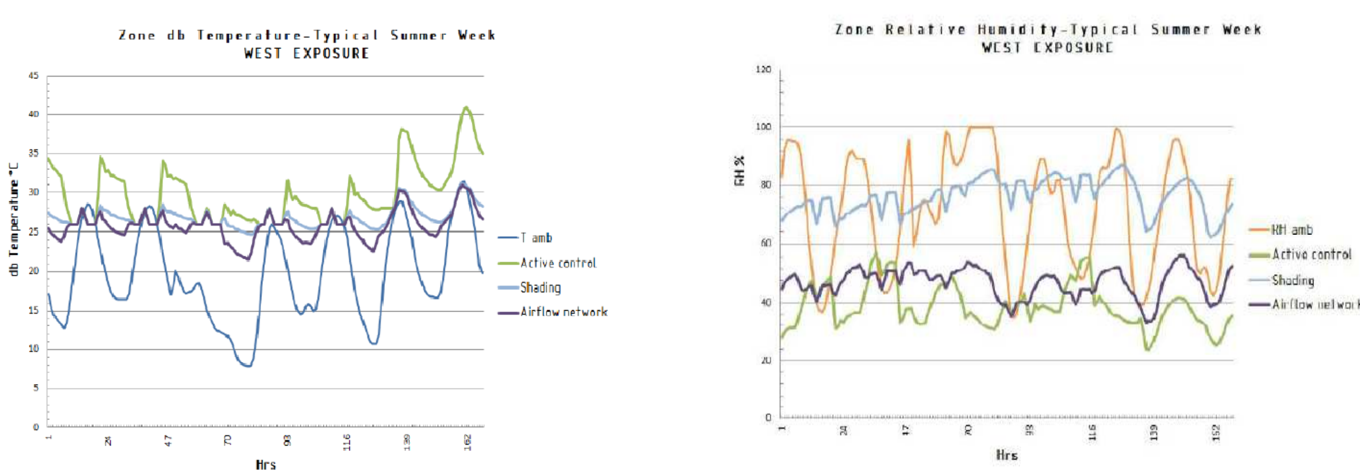


Fig. 11. Zone Dry bulb Temperature(a) and Relative Humidity(b) comparing three different strategies to reduce summer overheating.

CONCLUSIONS AND FURTHER RESEARCH

This research shows a methodology for evaluation of full scale building energy behaviour considering results obtained from monitoring activity and dynamic simulation. Simulation tools allow to investigate different scenarios to improve the building performance and comfort indoor.

An important aspect considered it has been the detail of the model simulation: in the case study it was decided to adopt "multi-zone" model to evaluate the environmental performance for a specific thermal zone and to extend results to the full scale the building . This approach offers the opportunity to verify the impact of a technological solution on the energy behaviour of a full scale building minimizing the complexity of the model simulation and consequently the possibility of making mistakes.

According to the results of model simulation of Department for Productive Activities, the main energy consumption is due to the new building (block 2). Considering the retrofit of building throught an improvement of thermal plant in order to reduce energy consumption, it is reasonable to introduce the active control for fan-coils only. In fact, installing an active control system on radiators of block 1 is much expensive because it is necessary to change the hydraulic connections on each unit to insert three-way valve. Considering the introduction of an active control in fan-coils of block 2, the estimated value of energy saving is about 25-35%. Installation cost for each room is 1100-1200 euro, and considering max 2 fan coils within a room, total cost would be about 40.000 euro. However, active control does not provide the solution to the problem of indoor discomfort due to the double glazing facades in office rooms located in block 2, especially in the summer period. In this case the the most cost-effective ways to improve building energy performance and comfort indoor is the building envelope retrofit through the investigation of different technological solutions for facades system.

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“LEED-Oriented” Projects in Mainland China and the Indication to Sustainable Practice in Developing Countries

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ABSTRACT

As one of the largest developing countries in the world, China is undergoing a period of massive construction. Meanwhile, the urgent energy intensity reduction agenda requires energy efficient and environmental friendly design to be implemented nation-wide. Specific guidelines and green building assessment system have been established in mainland China. This study will review two LEED awarded projects in southern and northern China, to reveal how the “LEED-oriented” practice came to success through decision-making, design strategies and specific system integration. The design team adopted new mindset and methods in their practice and benefited the projects: 1. Pre-project decision-making; 2. Performance-based design; 3. Integrated system approach. Energy efficient systems and green design features introduced great customer experience with low energy cost. The paper offers technical project details. Quantitative data from post-occupancy survey are provided to investigate the actual performance of the operating systems and explore the possible issues; occupant satisfaction is also being studied. Through case projects, it was showed that leading edge green building assessment systems help to identify the general structure for environmental issues and increase public awareness in developing countries. Certain limitations of existing practice are discussed, and suggestions on enhancing green building design practice in developing countries are summarized.

INTRODUCTION

China is one of the biggest developing countries in the world and facing the challenging energy and environmental issues. Estimated by the World Bank, half of the world’s new construction will take place in China up to 2015. With such rapid developing speed, the released International Energy Outlook (U.S.EIA, 2011) predicted that about 50% of energy consumption grow will be come from China and India in the next 2 decades. At the same time, national and local environmental problems have manifested along with the resources shortage. Eight of Chinese large cities have been rated as the top-ten air pollution cities in the world; nearly 2/3 cities in China facing water shortage and in particularly severe areas water resource per capita only reaches 4% of the world’s average. With all the above and similar developing issues and problems being brought to the surface, the Chinese government has announced an aggressive energy intensity reduction agenda which has set the carbon emission reduction target to be 40%-45% up to 2020, comparing to the 2005 standard. In China, about 25% of electronic use goes to building consumption including lighting, cooling, heating and cooling. The energy reduction target sent a strong signal to the industry to speed up the “green building evolution”. The rising attention and the government’s support have driven the environmental practice in China and as well as the development and implementation of building code and green building evaluation systems.

Local green building evaluation systems have been established in China. The Green Building Evaluation Standard (GBES) was created in 2006, and in 2003 the Building Assessment System of 2008 Green Olympics was developed to offer guidance on green practice in stadiums and supporting facility construction for the 2008 Beijing Olympics event. At the same time, several comprehensive foreign evaluation systems have entered China; the most well-known “Leadership in Energy and Environmental Design” (LEED) system has rapidly dominates the market of green building certification in the recent years. Based on the most updated data posted by USGBC, for the top ten countries with offshore LEED projects, China is at the third place; there are 1156 registered and certified projects in mainland China with the total building area being 66.5 million gross square meters. In the certified projects, nearly 70% were awarded LEED Gold or LEED Platinum. Professionals in the industry also endorse the system, the number of LEED GA and LEED AP reached 1,092 (1% in the world) in mainland China, ranking at the third place. 30% of these registered LEED professionals are architects; the rest are consultants, planners, engineers, and interial designers. It can be seen from these data that LEED system has leading the field of green building evaluation in mainland China.

With LEED and its method been introduced to offshore areas, questions have been arise on how does the system address the “acclimatized” issues in developing countries, especially some Asian regions with distinct cultural context. More research attention should be placed on strategies of refining the green building evaluation systems to better serve the industry and promote the green development in these developing countries.

Figure 1 left: Vanke Center (Shenzhen) was certified LEED Platinum award; right: Linked Hybrid (Beijing) was certified LEED ND award

OBJECTIVE AND METHODOLOGY

Through two "LEED-oriented" projects in mainland China as case study, this paper would first demonstrate how pre-project target setting and performance-based integrated design let to LEED-awards and occupant satisfaction. Secondly, base on post-occupancy survey, actual energy performance of the LEED-certified buildings will be investigated. Project information including technical details, energy data, operation cost, and occupant feedback will be revealed in the paper. Successful target-oriented working mindset of these cases will be summarized and how far would the LEED system guides the projects to the energy-efficient outcome and some possible limitation will be discussed. Suggestions on refining the green building assessment systems in developing countries will be offered at the end of the paper.

CASE STUDY: LEED-ORIENTED PROJECTS

The two LEED-awarded projects selected for case study are the Linked Hybrid, Beijing and the Vanke Center, Shenzhen (fig. 1). Steven Holl Architects designed both projects with consistent design mindset. These two projects locate in different climate zones and facing varying environmental issues; yet pre-project target setting and performance-based integrated design successfully let the projects to LEED awards. The Vanke Center, Shenzhen and Linked Hybrid, Beijing are rewarded LEED Platinum and LEED ND respectively.

1. Pre-Project Decision Making

In both of the projects, client and the design team had set their goal on LEED award at the pre-project stage and the green design strategies were worked out based on the environmental structure in LEED. Showing in Table 1 is the crosscheck shortlist of the rating environmental aspects in LEED and the green design strategies in Vanke Center.

Table 1 LEED-based green strategies employed in Vanke Center

Required Aspects in LEED	Green Strategies in Vanke Center	
	Design aspects	Systems and strategies applied
Sustainable Sites	Sustainable site selection	traffic, climate, and views
Water Efficiency	Water saving	rainwater collection and grey water system
Energy and Atmosphere	Building forms	floating structure for ventilation,
	Envelop design	Adjustable shading system
	Energy systems	thermal energy storage technique CO2 monitoring system under floor air distribution system solar water heaters and PV panels ground level greening and slope green roof efficient lighting design
Materials and Resources	Materials	local and renewable materials recycled and reused products waste management and reclaiming in construction
Indoor Environmental Quality	Indoor quality	low-radiated materials Adjustable ventilation system

The expectation on the "green performance" of the project had been welled defined at the pre-design stage. With the clear target, the green design of the project was improved and the efficiency of design-construction process was increased.

Despite the significance to the industry, green practice is at the starting stage in many developing countries. From the Vanke Center case, it can be seen that LEED offers comprehensive direction and clear environmental structure for green practice in developing countries, and greatly speed up the local green development.

2. Performance-Based Design and System Integration

The second case is Linked Hybrid, Beijing, which was awarded LEED ND in 2011. The selling point for the apartments in Linked Hybrid was the 'constant temperature and humidity' living environment: comfort and relatively constant thermal environment would be provided in the apartment with the temperature ranging at 20-26℃and humidity within 30-70%; acoustic control at 35-45db level. This performance was achieved by the system-integrated design. One set of geothermal power system, ceiling radiation, and the fresh air supply system offer comfort indoor experience and outstanding energy performance in Linked Hybrid.

- Geothermal Power

In Linked Hybrid, a large geothermal heat pumps system has been installed to achieve high energy efficiency. Geothermal system is known as the most advanced energy utilization plan; it takes advantage of the temperature consistency and heat storage of the earth. The system CUP can be as high as 5-7; while air-conditioning usually has CUP of 2.5-3.

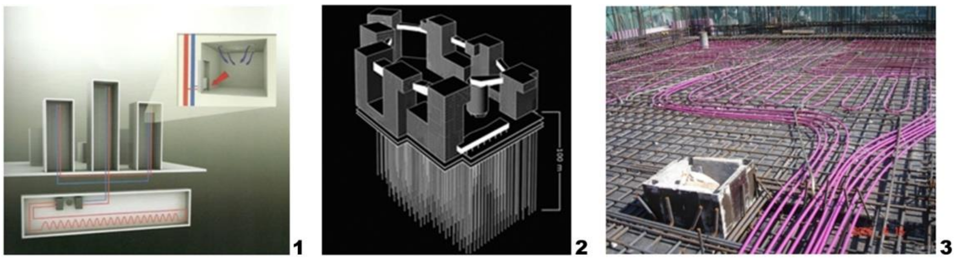

Figure 2 System integrated design in Linked Hybrid. (1) Combination of geothermal system and ceiling radiation system in Linked Hybrid; (2) The geothermal system installed right under the foundation of the Linked Hybrid apartments; (3) Water pipe layout for ceiling radiation system (under construction)

A typical geothermal heat pump system includes 3 parts: the ground heat exchanger, the heat pump unit, the delivery system. In Linked Hybrid, the ground exchanger is formed by 632 water pipes. The system buried right under the garage floor and reached 100m deep. The geothermal system uses the PE “DN32 double-U” pipes to run the water, which are lying every 5m in grid array, between the anti-floatation piles. This is a closed-circuit loop, and materials with large heat conductivity is used to fill up the gaps surrounded the heat exchange pipes. Every loop is formed by 6-8 water pipes, and 5-6 loops are ended in one water supply and return header. PE pipe with an expected 50-year life circle were employed to minimize the maintenance; and during construction the pipes had gone through multiple pressure tests. If leakage happens during operation process, the particular loop in problem can be shut down in the inspection camber. By placing the system right under the building’s foundation (See fig.2), Linked Hybrid project started the practice of installing geothermal heat pump in core urban areas.

With its delivery system, the geothermal power offers constant indoor comfort for apartments in Linked Hybrid. There are 8 heat pump units in the system, 4 units are used to heat up/cool down the fresh air ventilates; while the other 4 units of 1200kw are used for the ceiling radiation system. In most of the year, the system works alone to supply cooling and heating to the 220,000m^2 in the neighborhood. Only in the coldest or hottest months, extra power supply from boiler and cooling tower would be needed. Water was circulated in the pipe array inside the ceiling structure and heat radiation from the ceiling would regulate the temperature in the apartment. In summer, 30 °C warm water is cooled down to 25°C by heat exchange with ground and further cooled to 18°C by the heat pump unit to circulate in the ceiling radiation system inside each apartment. In winter the original water temperature was 3°C and would be heated up to 8°C by the ground heat and goes up to 31°C by the heat pump unit. To deal with the peak period, 2 refrigerators of 2000kw would be added to assist the geothermal heat pumps and cool the water to 7~12°C in mid-summer. For the coldest months, 4 boilers of 1400kw would be provide extra power support; and 45~50°C water will be running in the loop system to offer radiation heating in the apartments.

The structure for the ceiling radiation system was formed by 2mm thick PB plastic pipes with the outside diameter being 20mm; all these piles were installed as a layer of the ceiling slab (see fig. 2 and fig. 3). The water circulated inside the loop is around 18~21°C for refrigerating in summer and up to 28~31°C for heating in winter. Inside the ceiling slab, the water pipes are lying more densely at the north side than the south to offset the difference caused by orientation; and a more uniform thermal environment will be created in the apartments. The year-round indoor temperature is between 20 to 26°C in the apartment. At the same time, the ceiling is insulated from other parts of the envelopes, such as the partitions and external walls to avoid heat loss.

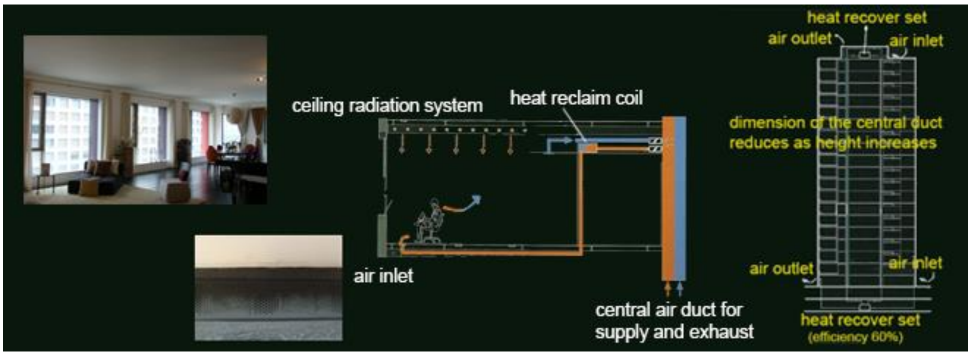

Figure 3 The separated indoor thermal regulation system (ceiling radiation) and fresh air supply system in Linked Hybrid *(modified based on Grand Moma by Steven Holl Architects, Beijing Press*)

In terms of indoor thermal regulation, the ceiling radiation is more energy-efficient comparing to the traditional air-conditioning system, as water has a larger heat capacity and is better medium of energy than air. To maximum the performance and energy efficiency, the thermal regulation system was separated from fresh air supply in the project. A "low turbulence, low mixing, low cooling" fresh air supply system was installed in the apartment. In each hour, 300m^3 volume of fresh air is sent to the apartment, which is much higher than the current national standard of fresh air supply (30m^3/person.hour). The system allows non-mixing heat exchange between the used and fresh air; 60% heat from the used air can be reclaimed by the system to pre-heat/pre-cool the fresh air before it enters the apartments. The geothermal system supports the heat reclaim set in the building. In summer, the fresh air is cooled to be 2°C lower than the indoor temperature and has been humidified. The section of the air shaft would become narrower every 3-4 floors to avoid air pressure decreasing and stabilize the wind speed (fig. 3). The design has saved both material and power on air pumping.

The system-integrated design has also been applied in the Vanke Center Shenzhen. In the project, an ice-storage system was employed to support the air-conditioning in summer months. The system uses electricity to make ice and store energy during night-time hours, and this energy will be released and provide cooling during daytime hours. The system has two advantages. First the system operates at night and avoids the load peak of the city power network. Second the system would have higher CUP comparing to air-conditioning cooling, as it uses water as heat medium instead of air. Under floor air duct network was installed to deliver the cool air to different components of the building. Cool air comes out at ground level and fills up the space up to about 2 meter height; such design increase the efficiency of the system as the cooling energy was distributed within the domain of occupant activity (fig. 4). A CO2 monitor is connected to the system and the airflow at the fresh air inlet would be adjusted based on the indoor air quality. Heat recover set was installed to collect waste heat from used air for fresh air pre-cooling.

Figure 4 The air outlets in the lobby and offices in Vanke Center

Vanke Center takes full advantage of solar energy. Solar water heaters and PV panels were installed on the large green roof (fig. 5). The solar water heaters supply hot water to the swimming pool and bathrooms. The large amount of PV panels is expected to provide up to 15 percent of the total energy need of the building and estimated annual output is 280,000 kilowatt-hours. The power generated by PV panel will support the dehumidification and refrigeration systems in the building.

Figure 5 Solar water heater and PV panels on the roof

Great amount of energy consumes on lighting in the office building (Irish Energy Centre, 1995). An efficient lighting design in offices can save energy remarkably. The project combines daylighting and high efficient luminaries and induced lamps in the lighting design. The building has large double-glazing facade to allow sufficient daylight to enter the offices. A set of perforated louvers is set up to provide certain level of shading to the facades, and its angle can be automatically adjusted according to the solar attitude or manually operate by occupants based on the need (fig. 6). Meanwhile, daylight has been integrated in the system where the requirement on stable lighting is less strict, such as underground parking; or in some places the daylighting is combined with the artificial light as a delicate supplement (fig. 6). Some of the open space was well designed so the source of nature lighting will not be blocked.

Figure 6 Left: the application of daylight in the lobby and underground space. Right: The external shading device and adjustable perforated louvers

3. Post-occupancy survey and occupant satisfaction

Rare data on post-occupancy building performance and operation cost was reported for LEED awarded buildings. Post-occupancy survey is essential for green design enhancement and reveals whether the systems and green design feature could function properly. Satisfaction of occupants and their behavior pattern in the buildings offers valuable reference for architects and benefits green practice.

The energy system in Linked Hybrid combines the geothermal power with boiler and cooling tower. The EMO manager of Linked Hybrid stated that in most of the year, the geothermal system could fully cover the neighborhood’s demand in cooling and heating. In the coldest and hottest months, extra support is applied. This system cost 50% more than a standard energy system, but running in low operation cost with outstanding energy performance. Table 2 shows the initial investment and operation cost of different energy systems in mainland China. A survey was conducted when the integrated system in Linked Hybrid had been running for 12 months to supply heating and cooling for total 220,000m2 areas. According to the Estates Management Office, the electricity peak occurred in January and February, during these winter months the operation cost of the system was 700,000RMB/month. A close number has been recorded in June and July. This number has already included the energy used for boiler and cooling tower, namely, it is the total cost for heating and cooling in winter and summer. May and October had the lowest consumption according to the records. The electric bill for these two months is about 350,000RMB/month. The annual operation cost on cooling and heating for this neighborhood was approximately 6,000,000RMB.

Table 2. Comparison on initial investment of different energy systems

Initial Investment		Operation Cost	
Gas turbine	8,300 RMB/KW	Gas	0.18 RMB/KW
Chiller/Heat pump	3,600 RMB/KW	Electricity	0.40 RMB/KW + 50 RMB/KW(peak)
Compression chiller	3,200 RMB/KW	Water cooling towers	14 RMB/m^3
DE-Absorption chiller	4,250 RMB/KW	CO_2-emission	4,250 RMB/KW
Cooling towers	500 RMB/KW	Gas	0.2 tCO_2/KWh
Boiler	450 RMB/KW	Electricity	0.9 tCO_2/KWh
Energy piles	2,000 RMB/KW		
Ground water wells	700 RMB/KW		

When the building was put into operation, the Vanke people were happy to see that the thermal storage system, the under floor air distribution system brought thermal comfort to the building and had a better energy performance with lot money saved on electric bills. The solar PV panels offer 15% of the power for the building and reduce the CO2 emission. Water saving strategy saves 30% of the total consumption. The innovation of the construction of the project saved 80,000,000 CNY budget.

To allow the user to be in control of comfort and operating the system is essential for saving energy and operation cost, and more importantly, to achieve occupant satisfaction. People can stand some degree of discomfort when they are in control of the conditions in their workplace (Cohen et al., 1999). Yet to what extend should the occupants be granted the control worth discussion. When user involvement is not appropriately designed, it can also result in wrong operation of the building and wasting energy. Leaman's study (1999) revealed that user reaction and response could be reckless sometimes, such as over-compensating for relatively minor annoyances, not choosing the most proper system to operate but instead the ones that are convenient to hand, and lacking responsiveness in adjusting the systems with the change of the environment.

In the Linked Hybrid case, occupants can regulate the temperature and fresh air supply by a controller inside the apartment, which has a limit though, considering the comfort range and energy consumption of the ceiling radiation system. The integrated system set the temperature range to be 21-22 ℃ for winter and 24-26℃ for summer, occupants can adjust the indoor temperature within 2 degree. When the apartment is unoccupied for couple days, the system can be switched off while small amount of fresh air will enter and circulate the space due to the pressure in the duct. So the apartment is still ventilated without extra energy consumption, and there won't be unpleasant smell when occupants come back days after.

The energy system of Vanke Center showed a slightly different picture. Data from EMO recorded the total energy output of the PV panels was 1358,460KWh since the building was put into operation, and the annual output of the system was 272000 kWh, reached about 97% of the expected value. According to a recent interview, the EMO stated that after 5 yearss' operation, the PV panel system has been malfunctioned and under repair. On the other hand, test result from 2013 revealed that the ice store air conditioning system had a low efficiency in ice making (less than 50%). The data above demonstrates the performance of the energy systems in Vanke Center are not functioning as designed.

Nevertheless, the design of Vanke Center values the comfort and satisfaction of the occupants. Great efforts were made on different aspects to meet the comfort range, including temperature, humidity, lighting and views. Occupants can flexibly control the working environment according to their personal needs. In the working space sparated lighting switch and a control panel for air conditioning are provided to each staff. "People working together in a big office usually have different needs for air-conditioning. a centralized cooling system hard to satisfy everyone and sometimes makes people sick. Now this is no more a problem to us." A staff claimed in the interview. Furthermore, everyone working in the building is more or less noticed the building's green features. It shows that understanding how the building operates and its quality of being environmental friendly brings additional satisfaction to the occupants.

DISCUSSION ON GREEN PRACTICE AND EVALUATION SYSTEM ESTABLISHMENT

These two case studies demonstrated that LEED and LEED-initial practice benefits a the green building development in mainland China, and the positive effects can be summed up as below:

1. The LEED system offers clear environmental structure for green practice and in developing countries;
2. Training process and technical support introduce knowledge input and increase the amount of local professionals;
3. Large and demonstration projects can promote international cooperation and communication between different expertise.

However, the high cost and large investment of these LEED-oriented projects make it difficult to widely adopt this mode in developing countries. Energy performance of some of the LEED projects are relied on high-tech systems, and these projects to some extend, neglect the passive design and environmental planning methodology. This, as revealed in the case study, has its shortcoming. Based on the above, suggestions on enhancing green practice in developing countries are summarized:

- climate-based passive design

A great portion of developing countries and regions locate in severe and harse climate zones. To identify the climatic issues and formula strategies of climatic design with passive approach is vital in these regions. It is regional-applicable and much less cost-demanded; and a larger cost-and-return ratio can be obtained from climate-based practice in these regions than it was in the moderate climate zones.

- energy efficiency of heating and cooling systems

As Chmutina (2010) has pointed out, improve the cooling and heating system can save up to 70% of energy in China; energy efficient heating and cooling system is essential for the green development in China. Since air carries relatively less energy per unit volume, it is not recommended as energy medium. Furthermore, the heating and cooling system should be separated from fresh air supply.

- standard setting and occupant behavior study

User involvement is essential for both energy saving and occupant satisfaction. The "comfort" standard should be set as an acceptable range instead of a neutral condition; at the same time allow the occupants to adjust the systems within this boundary. It can firstly let the user have the control, and secondly avoid energy waste caused by overreaction of the users. At the same time, branching and operation systems are preferred to centralized control.

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Session PE : Materials

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Faith - Knowledge Consortium of Gujarat

Survey on electrical energy use in Asia office facility and economic analysis through the application of Battery Energy Storage system (BESS)

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Topics: Control Techniques for Energy Management, Building Reuse and Refurbishment
Keywords BESS, Building energy, Peak Shaving, Electric energy, Energy pattern

ABSTRACT

The battery energy storage system (BESS ENERGY STORAGE SYSTEM) is afford storing electric energy of the light load zone release time of the maximum load that may be referred to enable the device .Technical problems in the past due to cost and practical application of the burden to have had a lot of trouble. Due to recent advances in electric vehicles and energy storage devices, the weight of the product density , and product price declines to bring such products to use the matching conditions favorable due to recent social product is applied in many areas and the study who being accelerated. The installation of the battery energy storage products is the maximum energy load of the building users and the required time for the charges to enable the effective use of energy in the building to ease the economic burden of the users have had the energy to give energy providers the burden on the facility expansion this can be a benefit by reducing each other can be described as a method. In fact, the electrical energy storage facilities near field can be said more, but the actual large office building in the applying existing facilities and use of electrical energy for the estimation of the amount provided by the Institute of Energy Research, public buildings energy relative coefficient is used to obtain and afford the actual usage pattern by comparing the work proceeds. Electric energy savings and light load hours of the base rate and the maximum load of the electric peak shaving time by looking at how much it costs to save energy costs and payback period of the initial investment products see if how much can be said for the research .

1. INTRODUCTION

Recent forms of distributed renewable energy power supply is enabled to store electrical energy in an energy storage device (ESS, Energy Storage System) is increasing the interest .The advent of high-density high-efficiency conventional rechargeable batteries store electricity in many areas, it is impossible to escape from what used to be trying to promote. The use of the electric energy storage technology, especially since the maximum power demand on the energy to move the load to a light load zone that enables the necessary electric power demand of the facility for enabling efficient operation. In terms of the power demand of the energy provider by enabling the administration of the generator and the environmental problems caused by expansion of the transmission and distribution equipment, such as to reduce the investment cost can induce a strategic electricity supply. Construction of the electrical energy storage system in order to examine the storage medium should be on the preceding study, regeneration of energy storage in order to find the most suitable medium and utilizing the analysis of the characteristics of each medium should be applied.

2. METHODS

In this paper, the basic structure of the ESS and the ESS for different kinds of features introduced and examined with respect to domestic and international market trends. In addition, ongoing trends related to domestic and international standardization want to analyze the characteristics of the system. These previous studies of one of the devices after the ESS technology applied to the BESS system by looking office building heating and cooling energy peak load management can respond effectively to make sure that after viewing the parties to this paper.

Due to changes in electricity tariffs rising cost of energy use in buildings

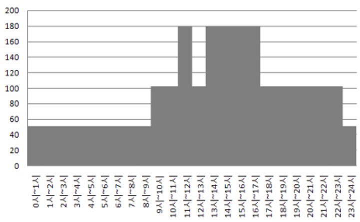
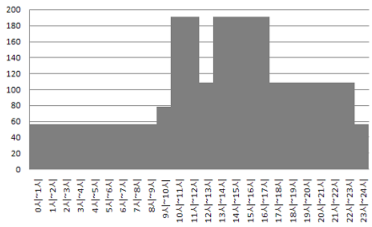
Analysis of the building's energy use patterns destination

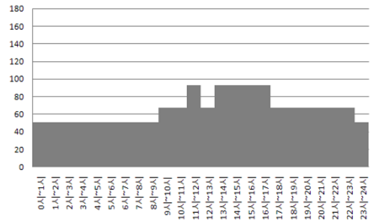
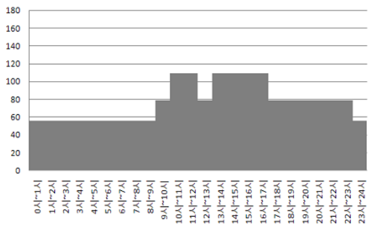
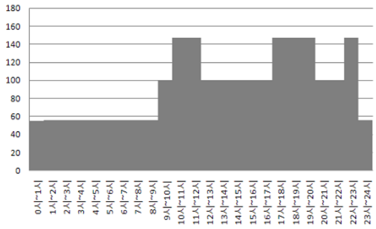
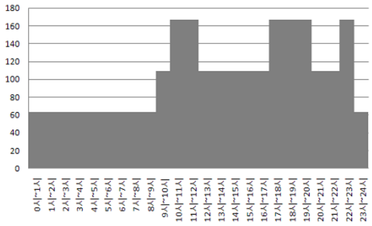
After application of the ESS destination building operational analysis

The resulting value of destination property derived

3. COST OF ELECTRICITY

If the time zone differential of seasonal fare and each season depending on the hourly cost of the power supply to charge a differential fee system can be said. In other words, in the case of the summer season, winter, spring, fall is divided into 24 time zones, separated by time sensitive afford each season, and the differential rates will apply. Korea Electric Power to supply the exclusive sales structure. Therefore, consumers can choose power bill narrow. Korea Electric Power provides electricity to the unit price, and the average fee structure by use of the following can be classified as shown in the table.

Energy price	~2012	2013
Summer Season		

Spring, Fall Season		
Winter Season		

4. ANALYSIS OF THE BUILDING'S ENERGY USE PATTERNS DESTINATION

4.1 Analysis

Location: Daejeon, 139 West seonsaro   Completion date: 12/10/1997

< Land area >   (Unit: ㎡)

Total	Construction area	Green area	Other areas
518,338	28,703	259,604	230,031

Building Structure: Steel Reinforced Concrete

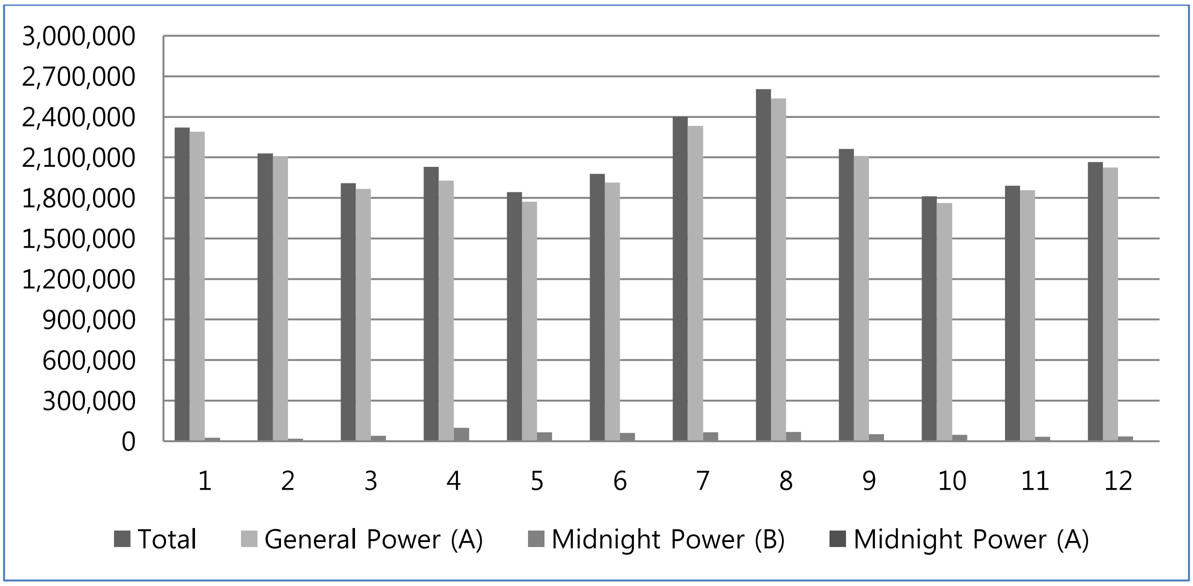
Building Size: 2 underground floors / ground 20 floors

Maximum height: 91.9m, Above is: 36.22N, The floor and: Typical floor 4.2m, up to 5.4m (ground floor)

4.2 Data

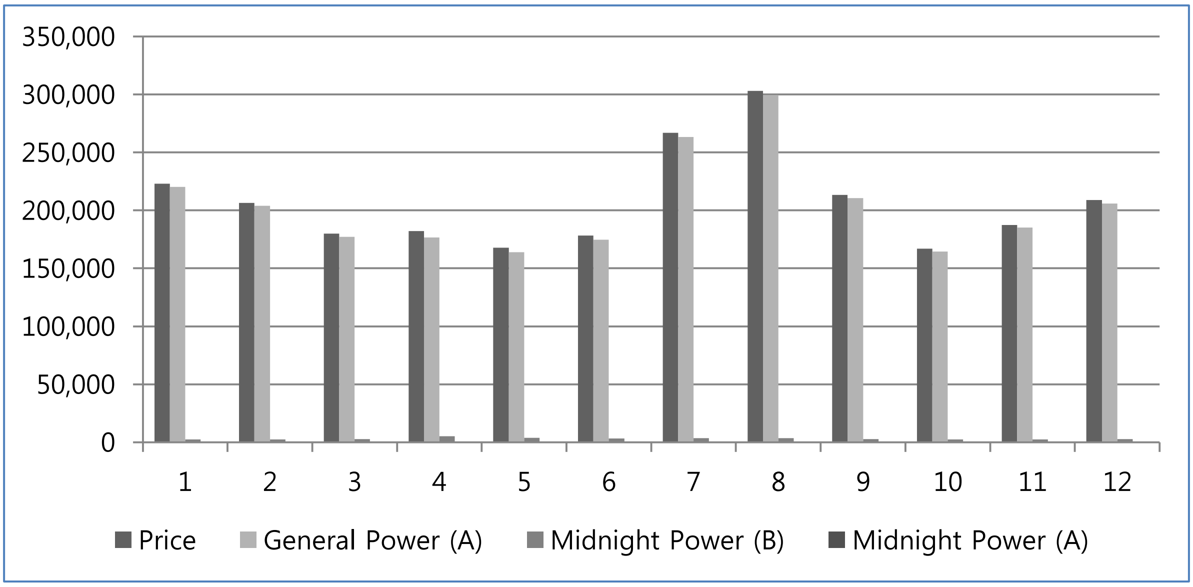
Monthly amount of electrical energy in 2009

(Unit: kWh)



Monthly amount of electrical energy price in 2009

(Unit: Dollars)

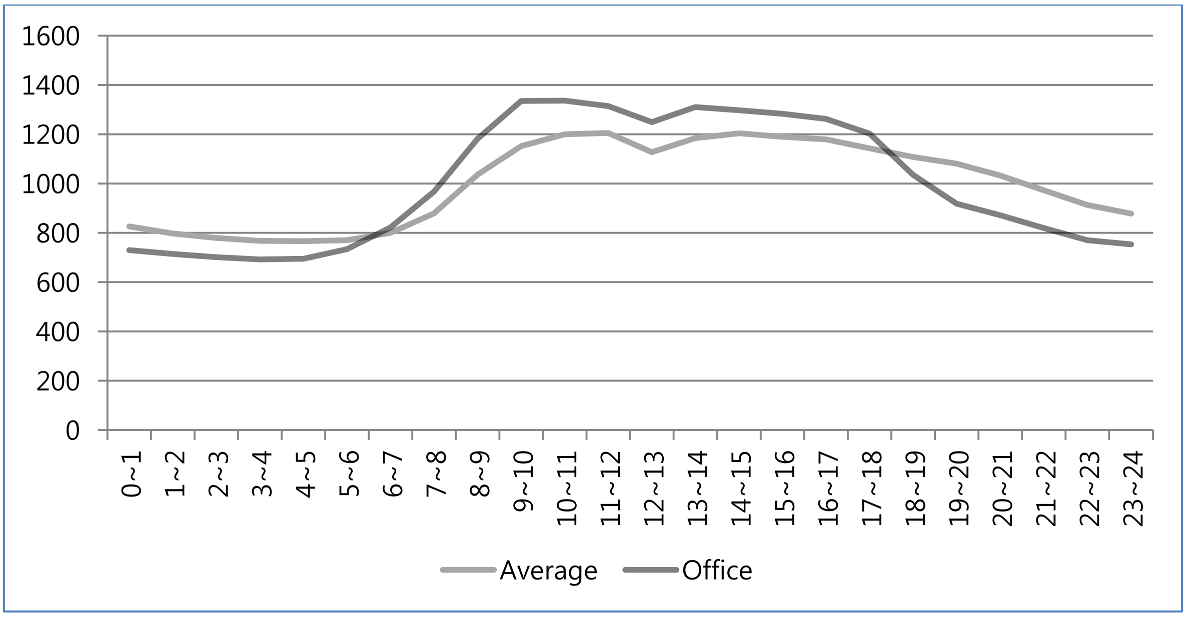


4.3 Solving the building energy use pattern

According to the data extraction KEPCO contract type sales database of customers to find out the average hourly power consumption can be seen. In order to calculate the predicted values relative load factor is the monthly Energy Management Corporation load pattern of educational holiday season working load pattern is used.

Load forecasting = peak demand × relative factor

24 hours relative load factor set to 1000, the average of each time slot representing a load index. How to calculate the relative coefficients are as follows. Classification by type of weekday working and living in the form of electricity usage behavior will be classified by considering the impact. National Day of the week from Tuesday to Friday, the day of the week, not working day-to-day work was set takes place. Working day by working day by day to show a different behavior on Sunday, Saturday and Monday were classified. Closed on Sunday conducted the day of the week as a whole , and performed according to the five-day workweek on Saturday and the other working day and appear in the form of the load is carried entirely closed on Sundays and also the load of the different forms of the need for analysis elsewhere there. 24 hours, the average load factor relative to the respective time slot 1000 is set to represent the low and high load index. Therefore, there is no unit . In order to forecast electricity usage statistics based on the classification of the contract type classification, hierarchical classification, one type-specific sorting, classification and utilization peaks were classified by type of case working days (not include holidays from Tuesday to Friday) Sunday, Saturday, Monday, and was used. If the seasonal peaks by use of classification was based on the peak day occurred. 75,684 of these data, the industry has been created on the basis of the distribution of the Classifieds.



4.4 Adapting BESS

ESS installed capacity of 90% compared to the average operating efficiency is assumed to keep the amount of planning time and was discharged afford.

※ 8:00 a.m. to 7:00 p.m. discharge time Average price: 1256.5kW

※ (load values-day average value -1256.5) of the load values: 1736.4 kW

Time	Load values	(Load values-Daily average values)	(Load values-Daily average values-1256.5kw)
0~1	3593.1	-1329.8	
1~2	3519.2	-1403.6	
2~3	3455.2	-1467.6	
3~4	3406	-1516.8	
4~5	3420.8	-1502	
5~6	3612.8	-1310.1	
6~7	4050.8	-872	
7~8	4764.5	-158.3	
8~9	5817.8	895	
9~10	6570.9	1648	391.5
10~11	6580.7	1657.9	401.4
11~12	6472.4	1549.6	293.1
12~13	6147.6	1224.8	-31.7
13~14	6452.7	1529.9	273.4
14~15	6388.8	1465.9	209.4
15~16	6314.9	1392.1	135.6
16~17	6211.6	1288.7	32.2
17~18	5921.2	998.3	
18~19	5094.3	171.4	
19~20	4523.3	-399.5	
20~21	4292	-630.8	
21~22	4036	-886.8	
22~23	3794.9	-1128	
23~24	3706.3	-1216.6	

CASE .1

Proper capacity planning: 1MW (taking into account the 90% efficiency usage is described 900kW)

CASE. 2

Proper capacity planning: 2MW (taking into account the 90% efficiency usage is described 1800kW)

CASE. 3

Proper capacity planning: 3MW (taking into account the 90% efficiency usage is described 2700kW)

Time	Daily use		Time	Daily use
0~1	3593.1		0~1	3850.6
1~2	3519.2		1~2	3786.6
2~3	3455.2		2~3	3614.3
3~4	3406		3~4	3545.4
4~5	3420.8		4~5	3496.2
5~6	3612.8		5~6	3614.4
6~7	4050.8		6~7	4050.8
7~8	4764.5		7~8	4764.5
8~9	5817.8		8~9	5817.8
9~10	6570.9	291.5	9~10	6313.4
10~11	6580.7	301.4	10~11	6313.3
11~12	6472.4	193.1	11~12	6313.3
12~13	6147.6		12~13	6147.6
13~14	6452.7	173.4	13~14	6313.3
14~15	6388.8	109.4	14~15	6313.4
15~16	6314.9	35.6	15~16	6313.3
16~17	6211.6		16~17	6211.6
17~18	5921.2		17~18	5921.2
18~19	5094.3		18~19	5094.3
19~20	4523.3		19~20	4523.3
20~21	4292		20~21	4292
21~22	4036		21~22	4036
22~23	3794.9		22~23	3794.9
23~24	3706.3		23~24	3706.3

Time	Daily use		Time	Daily use
0~1	3593.1		0~1	3984.5
1~2	3519.2		1~2	3920.6
2~3	3455.2		2~3	3748.3
3~4	3406		3~4	3406
4~5	3420.8		4~5	3694.2
5~6	3612.8		5~6	3822.1
6~7	4050.8		6~7	4186.4
7~8	4764.5		7~8	4796.7
8~9	5817.8		8~9	5817.8
9~10	6570.9	391.5	9~10	6179.4
10~11	6580.7	401.4	10~11	6179.3
11~12	6472.4	293.1	11~12	6179.4
12~13	6147.6	-31.7	12~13	6147.6
13~14	6452.7	273.4	13~14	6179.4
14~15	6388.8	209.4	14~15	6179.4
15~16	6314.9	135.6	15~16	6179.4
16~17	6211.6	32.2	16~17	6179.4
17~18	5921.2		17~18	5921.2
18~19	5094.3		18~19	5094.3
19~20	4523.3		19~20	4523.3
20~21	4292		20~21	4292
21~22	4036		21~22	4036
22~23	3794.9		22~23	3794.9
23~24	3706.3		23~24	3706.3

Time	Daily use		Time	Daily use
0~1	3593.1		0~1	4109
1~2	3519.2		1~2	4045
2~3	3455.2		2~3	3872.7
3~4	3406		3~4	3498.7
4~5	3420.8		4~5	3818.6
5~6	3612.8		5~6	3946.6
6~7	4050.8		6~7	4310.8
7~8	4764.5		7~8	4921.1
8~9	5817.8		8~9	5817.8
9~10	6570.9	491.5	9~10	6055
10~11	6580.7	501.4	10~11	6054.9
11~12	6472.4	393.1	11~12	6054.9
12~13	6147.6	68.3	12~13	6054.9
13~14	6452.7	373.4	13~14	6055
14~15	6388.8	309.4	14~15	6055
15~16	6314.9	235.6	15~16	6054.9
16~17	6211.6	132.2	16~17	6055
17~18	5921.2		17~18	5921.2
18~19	5094.3		18~19	5094.3
19~20	4523.3		19~20	4523.3
20~21	4292		20~21	4292
21~22	4036		21~22	4036
22~23	3794.9		22~23	3794.9
23~24	3706.3		23~24	3706.3

4.4 PROFITABILITY ANALYSIS

DOE's Sandia National Laboratories in the U.S. and launched in December 2012 ES-Select program, which was used as a database for information on battery storage system is as follows: Looking at the graph data 1kWh report if the price of $ 600 provided by the DOE, which shows the price of lithium ion in the price of industrial facilities and container type is determined by the middle of $ 400 was calculated assuming that the payback period. $ 400 per 1kw converted to the current exchange rate at the price of 440,000 won per 1kW to 2MW estimate of 880 million won in the case of the configuration was assumed to be costly.

CASE 1	Original A	ALT B	A - B
Base rate	657,047	630,290	26,757
Using amount	2,602,439	2,496,469	105,970
Reduce amount	14,152 dollars/ year		

CASE 2	Original A	ALT B	A - B
Base rate	657,047	616,941	40,106
Using amount	2,602,439	2,443,511	158,928
Reduce amount	20,783 dollars/ year		

CASE 3	Original A	ALT B	A - B
Base rate	657,047	604,431	52,616
Using amount	2,602,439	2,394,132	208,307
Reduce amount	26,972 dollars/ year		

CONCLUSION

Proceed in this study, the largest electric energy for the purpose of attention is focused on the investigation at this time and through the analysis of BESS actually have any effect on the building knowing about view. In fact, using the coefficient of relative configuration to look at energy usage and the actual usage is quite similar to the value estimate was confirmed. This allows the using of the monthly amount of electric energy consumption and in the process configuration. 3-4 hours in the case of ESS equipment to maximize the efficiency of the product can have an office building, the M -shaped energy load because it has a tendency of electric discharge by a particular time in a simple way, that there is a limit and then derives an analysis was . In the case of ESS equipment prices are falling faster in the state, but I think at this point, when the basis of a longer period of time had recovered. Future due to the rising cost of energy is electric charge realized the work is ongoing at the time BESS electricity rates will be rise building is an important element to be operated is obvious. In fact, users using BESS is to reduce the total amount of electrical energy , but not at the national level and a personal level to adjust the amount of load that can be used to reduce rates because they can serve as positive role in society generally we look forward to .

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Optimizing energy through on-site reuse and recycle construction waste in residential project – A Case Study of Pune

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ABSTRACT

India is a growing to become world's third largest construction market by 2025. It is also accounting for 11% of India's GDP after agriculture in country. Construction material waste is generated during any new construction, renovation, demolition of buildings and infrastructure projects. Virgin material, after extraction, cannot be used in its original state for building construction. It undergoes processing, which involves consumption of energy in terms of manufacturing or finishing, transportation, etc. The construction waste is a by-product of construction process. Construction waste has embodied energy and also needs energy for its disposal in term of transfer to dumping sites, which affect the environment adversely.

The study on practices and procedures to reuse the waste on-site and maximize use of recycled material is important with a view to minimize possible usage of virgin material in construction process. For the purpose of this research, the construction process and practice of residential projects is considered. As 80% of the residential projects in India are executed through conventional construction process, it is imperative to observe and recommend appropriate methods of construction activity to optimize energy usage. Categorically large infrastructure project and large scale housing projects are not considered, since it has an alternative of pre-cast / prefab construction method. It is beyond the scope of this research

The research paper focuses on the energy involved in construction waste and deriving strategies for reusing and recycling of the same. It also identifies the causes of generation of construction waste along with the quantity of waste generated on-site at different stages of conventional construction process. This study will helps to encourage possible on-site practices and procedures to minimize the waste and to utilize the embodied energy involved in construction waste.

INTRODUCTION

India is growing to become the world's third largest construction market by 2025, as per a study by Global Construction Perspectives and Oxford Economics[i]. Today the construction industry is the second largest industry of the country after agriculture and it is accounting for 11% of India's GDP[ii]. The Indian economic environment and system and procedures would further enhance construction industry, as it provides the basic physical infrastructure for the nation as well as other industries.

In India, construction industry is not just the fastest growing industry but largest in terms of investment, volume of natural resources consumed, volume of materials and products manufactured, employment generated and environmental impacts, etc. Along with development, construction industry carries several challenges like emissions to air, land contamination, noise pollution, waste disposal and discharges to water[iii].

Due to huge consumption of construction materials, huge amount of construction waste is generated during construction.

The construction and operation of the built environment has been estimated to account for

- *12-16% of fresh water consumption;*
- *25% of wood harvested;*
- *30-40% of energy consumption;*
- *40% of virgin materials extracted;*
- *20-30% of greenhouse emissions;*
- *40% of the total waste stream of countries, 15-30% of which ends up in landfill sites;*
- *Up to 15% of purchased materials at jobsite ending up as waste.*[iv]

From above percentage, it is seen that the problem of landfill waste needs to be given top priority and has to be tackled as soon as possible, by finding strategic solutions to the problem. The construction waste dumped on landfill site, leads to soil pollution which affects soil fertility and also leads to sub-soil water pollution. Random dumping of these wastes leads to air pollution and degrades the air quality.

The construction waste involves energy in extraction, manufacturing process, transportation to construction site, construction process, finishing and transportation to the landfill sites. Construction industry needs to address this issue and re-examine their construction processes and practices in this regard.

METHODOLOGY

This paper explains the need of optimizing energy in construction projects and establishes the relationship of embodied energy in building material and the los of same through construction waste. It further discusses material losses on construction site in Indian context through having an adverse effect on embodied energy and correspondingly cost of the project.

This paper quantifies construction waste generated at different stages of construction process through case study method. The method adopted for understanding the market practices of waste handling is through interviewing professionals like Project management consultants, Architects, Civil Engineers, and Contractors working on the site. The outcome of the interview is tabulated in percentage of waste material with respect to the total quantity of specific material purchased on site for concerned project..

The study also quantifies the wastage through cost implication and also in terms of total embodied energy of the material. It then suggests strategies and recommendations for construction practices to reduce construction waste generation and also recomends procedures for reuse of construction waste material.

The research then identifies the quantum of the material that can be reused and reclyed on site and make practicing recommendations for the same. It further estimates the respective embodied energies that could be saved by implementing recommendations.

To conclude, it emphasizes on the need in selecting appropriate material including size.

NEED OF OPTIMIZING ENERGY IN CONSTRUCTION PROJECTS

Pune is one of the fastest growing metropolise in India. Most of the construction projects in Pune adopt conventional construction practices of in-situ construction. These practices are most suitable to the stakeholders in the industry as workers are easily available. The stakeholders try to incorporate advanced technologoies like design mix, pre-cast RCC members in the construction process. But they do not ensure no-wastage of materials on account of certain reasons. Unskilled labor is being one of the common reasons.

Construction waste occupies considerable storage space either on the road, river beds, hill slopes and land fill sites. The major environmental impacts caused by these wastes dumps have an impact on surrounding landscape. Since construction projects are going-on in most parts of the city including re-development projects in old limits of PMC and new projects in peripheral areas, increased amount of construction waste dumped randomly is evident.

As many of the landfill sites are already being exploited, the disposal of construction waste is an issue that has been seeking attention within both the public and private sectors in Pune city. The increasing costs of disposal gets reflected in project costs, as contractors have to incorporate anticipated disposal costs in their bid costing. Based on above fact, the emphasis is given for initiatives to reduce waste during construction activities to save environment and energy.

ENERGY USE IN BUILDING -

The energy usage in building is at four stages

1. Pre-construction stage – Energy in pre-construction stage:
   - To extract & process the raw materials, manufacture the building material
   - To transport the raw material from origin to manufacturing unit
   - To transport finished material and components from manufacturing unit to construction site
2. During construction stage - Energy used during construction process:
   - To operate machinery on job-site
   - For movement of vehicles on job-site to carry out construction process
   - Human energy on job-site

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3. Post-construction stage - Energy used in collection, segregation and disposal of waste after construction process is over
- Transporting waste material to designated location to reuse or recycle or landfill site for disposal
- Energy used in reusing or recycling the waste
- Energy used in process of material reuse

4. Operation of building - Energy in operation is the energy used once the building is occupied.

The focus of this paper is on energy used during construction stage and at post-construction stage. The energy used to dispose of waste material is also considerable in complete construction process. The energy in disposing waste can be minimized to greater extent by reusing or recycling the waste material.

CONSTRUCTION WASTE -

Construction waste is produced in large quantity by infrastructure projects, renovation or demolition of structures, etc. There can also be non-hazardous by-products generated. Waste is generated during site preparation, material use, material damage during handling, material non-use, excess procurement and human error.

Components of Construction waste debris typically include concrete, sand, aggregate, plastic, flooring material, rubber sealants, glass, metals and metal alloys, wood and wood based products, masonry material etc. Land clearing debris, such as weeds, rocks is also included in construction waste.

ENERGY OF CONSTRUCTION MATERIAL – EMBODIED ENERGY

The embodied energy of a product includes the energy used to manufacture it all through the process of mining or harvesting the raw material, refining, processing, and various stages of transport, to the finished product at the factory gate. The process of analyzing and quantifying the energy associated in these steps is part of Life Cycle Assessment of the building. The scope of this research is limited to the estimation of embodied energy involved in construction waste during construction process. The Life Cycle Assessment of that specific building material is out of the scope of this paper.

Energy consumption for the transport of manufactured products from factory to the site can have a large role in the total energy calculations. The energy consumption on the building site includes mechanical and human energy required for mixing, transporting, placing, finishing and cleaning, etc. The amount of energy used on the building site has increased considerably in recent years as a result of increased mechanization and increased labor cost.

MATERIAL LOSSES AND WASTAGE ON CONSTRUCTION SITE

Every material has "loss factor", which describes how much of a particular material is typically lost during storage, transport and installation of final product.

The estimated material waste percentage differs as per construction material. The total amount of material purchased on the project site is as per this ´estimated quantity.

Table 1: Estimated wastage of construction material [v]

Sr. No.	Type of material	Estimated wastage
1	Cement	2 %
2	Sand	10 %
3	Aggregate	5 %
4	Concrete structural	2 %
5	Concrete binding (lean)	10 %
6	Reinforcement steel bars	3 %
7	Reinforcement steel mesh	10 %
8	PVC sheeting	15 %
9	Steel for windows	7 %
10	Timbering in trenches	5 %
11	Stone masonry	5 %
12	Marble lining	20 %
13	Wood for door frames	5-7.5 %
14	Wood for shutters	10 %
15	Wood for flooring / walling	5-10 %
16	Sheet roofing	2.1-2 %
17	Tile roofing	5 %
18	Floor railing	2-5 %
19	Wall tiling	3 %
20	Pigments (colors other than natural grey)	5 %
21	Paints	5 %

CASE STUDY OF PUNE - CONSTRUCTION WASTE GENERATED AT DIFFERENT STAGES OF CONSTRUCTION PROCESS

A residential project is studied to quantify the waste material generated on site. The study involves the quantification of waste in terms of embodied energy of material waste as well as in monetary terms.

Project details

- Project type – Residential project
- Location – Kondhwa, Pune
- Plot area – 22300 Sq. M.
- Built -up area – 12542.00 Sq. M.
- Number of buildings – 4 Numbers
- Number of Floors per building – Parking + 11 floors
- Ground coverage 4 buildings – 1688.43 Sq m (522.45 Sq m – 01 Tower
388.66 Sq m – 03 Towers)

Refer table 4 for details of construction material purchased, material used for construction of buildings and quantity of waste generated during the construction process of the case study. The maximum wastage of material that is observed is of sand i.e. 24.50%. Tiles have about 16.67% wastage, where as masonry, steel and aggregate has 11.82%, 8.62% and 10.81% respectively. The least wastage is observed of PVC conduits i.e. 7.70%.

This study deals with wastage of concrete and mortar material (residue) and not the raw material (cement, sand and aggregate) separately. However handling losses of waste materials are not considered.

It is observed that there is a difference in percentage of waste material from literature review vis-à-vis to the one on site (case study). In such case the percentage from literature review is considerd as reference (base line).

Along with this, the material cost is also calculated. For this the current market rate is studied from Pune city. The calculation shows that, the cost of construction waste is 11.60% as compare to the total amount of material purchased. This increases the project cost and so as selling cost of residential unit. Refer table - 5 for detail calculations.

The use of embodied energy involved in construction waste is calculated and analyzed. The wastage of steel, concrete, cement and conduits is very less as compare to sand and aggregate, but the embodied energy involved in this wastage is very high. Also the embodied energy involved in tile and masonry wastage is also considerable. Refer table - 6.

RESULT

The calculation for case study shows that, the amount of construction waste generated on construction site is @17.50% with respect to the total material purchased on site for the project. It involves @11.60% of the purchased material cost. Also the embodied energy of construction waste is @10.70 % of the purchased building material on project site.

The material waste generation in conventional construction process is huge in monetary as well in environmental impact terms. Thus, cost saving potential and the reduction in environmental impact due to construction waste should be taken into consideration by adopting suitable measures for construction waste reuse and recycle.

STRATEGY

The reduction of construction waste generation is possible by preparing Waste Management Plan and implementing it during and after construction process. Following are some of the recommended practices and procedures for reuse of construction waste that can be adopted in Indian scenario.

RECOMMENDED PRACTICES AND PROCEDURE FOR REUSE

- The specification and quality of construction material plays important role in waste generation during the construction process. It also affects the quantity of material consumed in the construction and finishing of building.
- To control the material usage in the construction process, the coordination among all those involved in the design and construction process from site selection to project completion is necessary. They should meet on regular basis and address the issues like dewatering operation from site clearing process and excavation for foundation, material delivery, its storage and use, solid waste management, vehicle and equipment management. Also, contractor and labor training should be directed in the complete construction process of the project.
- The quality work affects lot in quantity of material usage and the waste generated in the construction process. Ex. The leveled surface of concrete slab to avoid use of screed material for tiling, masonry work in plumb to avoid excess

plastering material.

- The formwork used in the concreting work affects the material wastage in construction process. The appropriate selection of formwork material i.e. instead of wooden formwork use of steel formwork, cause less wastage of concrete. The smooth finish of using steel formwork reduces the quantity of plastering mortar and finishes the surface.
- Waste from one activity can be used as raw material for another activity. Site management with parallel activities need to organize to reuse and so as to reduce the waste
- Mandatory segregation of waste material / debris on site to reduce mixed construction material waste
- Material storage
  i. Construct temporary material yard for separate storage of different materials. This reduces the mixing of materials stored on construction site.
  ii. Store the material on water tight raised platform. This will save material at lower level from mixing in soil to avoid land contamination
  iii. Cement bags stored directly on floor are vulnerable to contact with waster and moisture which leads to wastage of material to greater extent

Table 2: Recommended practices for reuse of construction material waste

S.N.	Waste material	Recommended practices for reuse of waste material on site
I	Block	To use as curbs to stop water runoff from garden area
		To construct pots for shrubs in terrace garden
ii	Tiles	To use tile adhesives for fixing tiles on leveled concrete slab, which avoids screed material use
		OR To use crush sand as bedding material for tiles
		To create Mosaic pattern in front of entrance door.
		To create pathways and walkway in the landscape area by using large and small pieces
		To create colorful fences around the flower beds
		To create reflective façade and terraces
iii	Concrete	To reuse concrete waste for temporary work or low-grade concrete work. This need parallel activities to plan on site.
		To recycle and use crushed concrete as aggregate for concrete
		To prepare lean concrete for PCC of compound wall, plinth filing, traffic movement
		To manufacturing paving blocks for lighter traffic movement
iv	Plastic	To recycle for re-manufacturing
v	Mortar	To use admixtures or plasticizers in mortar to reduce re-bounce waste
		To collect mortar at the end of day and pour in water to reuse it by crushing and adding cement for lower grade work of next day
		To collect mortar at the end of the day and mix in sand in proportion of 1:4. Use it for next construction work
vi	Packaging material	To collect and segregate the material at job-site. Send it for recycling. Do not store in contact with of water and moisture as it spoil the material
vii	Soil	To manufacture Stabilized mud blocks to be used in some other projects
		To use clay blocks for fencing around the trees or shrubs in landscape area of the project or in the terrace gardens
		Preserve top soil and do not mix with other construction waste. After the construction process is over, it can be used for landscape purpose on same or other site
viii	Brick	To use for paving in landscape
		To use as plinth filling material
		To construct curbs in landscape area to protect top soil run-off
		To construct Brick bat-coba for terraces and toilets
		To construct raised platform within building or project landscape area as a filling material
ix	Water	Save water by using gunny bag / cork bags for curing of concrete work
		Use curing compounds in concrete work
		Reduce water use by fixing water meter / water controller at pouring point into concrete mixer. This helps to maintain the quality of concrete.
		Collect cement mixed waste water through properly sloped trenches in sedimentation tank and reuse for construction work
x	Steel	To reuse 20mm diameter and above small length bars after coupler binding
		To send for recycle as it is recycled 100%
		To use sheering machine for steel cutting. This helps to reduce steel waste
xi	Paint	To use good quality paint to reduce consumption by quantity at source (minimum coats give perfect shade)
		To appoint skilled labor to use paint properly and reduce waste
		Good quality of plastering reduces the excess consumption of paint
xii	Rock from Excavation	To break with the help of crusher
		To use large size stone for construction of compound wall
		To reuse small size stones as aggregate
		PCC from crushed stone to reduce source material consumption

ESTIMATED QUANTITY OF REUSED MATERIAL AND EMBODIED ENERGY

The construction waste can be reused for various site development activities in the same project. The quantity of construction waste that can be reused for different construction stages is calculated and the embodied energy involved in reused waste material is calculated. Refer to table 4 and table 5. The cost of construction waste against the total material purchased for project is 11.60%. This is large investment in construction waste. See table 6 for detail calculations.

Refer to table - 7 for the detail calculations of quantity of construction waste reused on same site for other construction activities. The masonry material reuse is up to 80.57% in brick bat coba filling for terrace and dry terrace of the residential units and the filling below deck area.

The quantity of concrete material waste can be reused up to 93.00% in lower grade concrete for paving blocks of open parking, plinth filling of club house and bedding material below walkway in open space.

The waste steel bars of diameter 8mm, 10mm, 12mm can be used for chair bars, pins in beam. Also steel bars of length 4'0" to 6'0" can be used for toilet slab and consecutive footings. This can consume up to 10% of steel waste quantity.

The segregated and preserved mortar waste can be reused for paver block bedding material. This consumes 13.12% of the mortar waste quantity.

The tile waste can be reused up to 13.12% in parapet top, Flooring of staircase landing at terrace level, Mosaic flooring design in front of entrance door of residential units.

These findings reveal that, up to 23.25% of total construction waste can be reused on same project. This help to save the quantity of virgin material required in the site development work for the same project. The remaining waste material can be reused on the other project site as per requirement of the work.

ESTIMATED QUANTITY OF RECYCLED MATERIAL AND EMBODIED ENERGY

The construction waste material can be recycled at job-site. The estimated quantity of construction waste that can be recycled is identified and the embodied energy involved in it is calculated. This helps to save the energy required in the manufacturing process of virgin material.

Refer table - 8 for the detail calculations of quantity of construction waste recycled on job-site. The steel waste that remains after reusing on site can be sent for recycling. Since steel can be 100% recycled, it can be sent to manufacturing plant.

The PVC conduit waste that generates from plumbing and electrical waste should be collect and segregated carefully and sent to the job-site. This can help to recycle 85% of PVC conduits for manufacturing of new product.

WASTE MATERIALS AND 3R -

Today the construction industry is facing the issue of Management of huge construction waste. This research recommends the ways to reduce, reuse and recycle of construction waste in Indian context. Besides a clear understanding of the general concept of waste, it is helpful to use a classification of waste in different categories, in order to understand the wide range of possible corrective actions related to its prevention.[vi]

The different construction waste generated on site can be reduced, reused and recycled. Following are the possible measures towards waste minimization by implementing 3R concept to different waste materials on construction site.

Table 3: Construction waste and 3R

Sr N	Construction waste	Reduce	Reuse	Recycle
1	Soil		✓	
2	Cement	✓		

3	Sand	✓	✓	
4	Aggregate	✓	✓	
5	Concrete	✓	✓	✓
6	Steel	✓	✓	✓
7	Masonry	✓	✓	✓
8	Wood	✓	✓	
9	Tiles	✓	✓	
10	Pipes	✓		✓
11	Aluminum	✓	✓	✓
12	Glass	✓		✓
13	Plastic		✓	✓
	Packaging material			
14	• Paint cans	✓	✓	✓
	• Cardboard boxes	✓	✓	✓

Most construction waste materials can be reused and recycled. Often, it is just a matter of separating waste, either on-site or off-site and sending it to the relevant waste stream.

Dedicated storage spaces should be allocated for the collection and sorting of waste. These spaces should be easily accessible to workforce and be in close proximity to waste collection points. Bins or storage containers should be allocated to accommodate different waste streams including reusable waste, recyclable waste, rubbish (non-recyclable waste). It is important that storage areas are conveniently located within a construction site.

Also, the initiative and training to labor is as important aspect. The labor should be aware of the signage/graphics on the waste-bins and contribute in sending the waste to relevant material waste-bins.

CONCLUSION –

In the construction industry, the materials are transformed into elements; elements are transformed into components, components into systems and building. Thus they define the flow of materials and energy during construction and are responsible for flows of materials and energy from building sites.

The construction waste is generated from the stage of site preparation to building services like plumbing, electrification of the construction process. The various waste materials like concrete, mortar, tiles, brick, packaging material, water are generated from these stages.

The embodied energy involved in construction waste can be reused up to 35.23% and recycled up to 26.74% with the recommended practices and procedures in this research paper. An important procedure like placement of different containers to collect and store the segregated wastes should be adopted on site. The maximum reuse of waste material will minimize the resource consumption for the construction material manufacturing. This will also save the cost invested in construction material.

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Table 4 - Construction waste of Case study – Residential project at Kondhwa, Pune

Sr. No	Waste material	Specification of material	Unit	Material purchased	Material used	Material Waste	% of Waste
1	Concrete with Portland cement	Structure, reinforced	Cu m	4526	4305	221	5
2	Mortar and plaster		Sq m	71446	64461	6985	10
			Cu m			126	
			Cu m		Total	347	
3	Crush Sand		Kg	6451200	4856090	1595110	25
			Cu m	3863		955	
4	River sand		Kg	4817400	3649147	1168253	24
			Cu m	3108		754	
5	Aggregate	Gravel	Kg	5665250	5052930	612320	11
			Cu m	3907		422	
6	Cement	Portland cement	Kg	2436450	2265040	171410	7
			Cu m	1624		114	
			Cu m		Total	2245	
		Net loss of Sand, Aggregate and Cement due to handling, storage and transportation				1899	
7	Steel	Galvanized from ore	Kg	570370	521200	49170	9
8	Masonry	Aerated concrete					
		Fired clay (well fired bricks massive) size 150 x 150 x 75	No	769340	678400	90940	12
9	Tiles	Ceramic tiles (9-21 kg/sq.m.)	Sq m	16800	14000	2800	17
10	Electrical conduit	Polyvinyl Chloride Pipe (dia 40 to 63 mm, wt 0.33 to 0.56 kg/m)	R m	45000	42000	3000	7
11	Plumbing conduit	Polyvinyl Chloride Pipe (dia 40 to 110 mm, wt 0.33 to 1.64 kg/m)	R m	23000	21000	2000	9

Table 5 - Cost effect due to construction waste

Sr. No	Waste material	Specification of material	Unit	Material purchased	Material used	Material Waste	Rate of material		Total Amount of purchased material	Total amount in waste material
							Unit	Rs per unit		Rs
1	Concrete with Portland cement	Structure, reinforced	Cu m	4526	4305	221				
2	Mortar and plaster		Sq m	71446	64461	6985				
			Cu m			126				
			Cu m		Total	347				
3	Crush Sand		Kg	6451200	4856090	1595110				
			Cu m	3863		955	Cu m	1100	4249293	1050671
4	River sand		Kg	4817400	3649147	1168253				
			Cu m	3108		754	Cu m	1950	6060600	1469738
5	Aggregate	Gravel	Kg	5665250	5052930	612320				
			Cu m	3907		422	Cu m	1050	4102422	443404
6	Cement	Portland cement	Kg	2436450	2265040	171410	Bag	320		
							Kg	6.40	15593280	1097024
7	Steel	Galvanized from ore	Kg	570370	521200	49170	Kg	48	27377760	2360160
8	Masonry	Aerated concrete								
		Fired clay (well fired bricks massive) 150 x 150 x 75	No	769340	678400	90940	Piece	4.50	3462030	409230
9	Tiles	Ceramic tiles (9-21 kg/sq.m.)	Sq m	16800	14000	2800	Sq m	400	6720000	1120000
10	Electrical conduit	Polyvinyl Chloride Pipe (dia 40 to 63 mm, wt 0.33 to 0.56 kg/m)	R m	45000	42000	3000	R m	20	900000	60000
11	Plumbing conduit	Polyvinyl Chloride Pipe (dia 40 to 110 mm, wt 0.33 to 1.64 kg/m)	R m	23000	21000	2000	R m	100	2300000	200000
									7,07,65,386	**82,10,227**
										12%

Table 6 – Embodied energy in construction waste

Sr. No	Waste material	Specification of material	Unit	Material Waste	Density of material (Weight per volume)	Conversion factor	Total Quantity	Embodied energy of material	Total Embodied energy in Waste

					Kg/m³		Kg	MJ/Kg	MJ
1	Concrete with Portland cement	Structure, reinforced	Cu m	221	2400		530400	1.50	795600
2	Mortar and plaster		Sq m	6985	1900	126 Cu m	238887	1.00	238887
									1034487
3	Crush Sand		Kg	1595110	1670		1595110	0.50	797555
4	River sand		Kg	1168253	1550		1168253	0.50	584127
5	Aggregate	Gravel	Kg	612320	1450		612320	0.50	306160
6	Cement	Portland cement	Kg	171410	1281 - 1500		171410	3.6 - 4.0 (3.8)	651358
									2339200
		Net loss of embodied energy of Sand, Aggregate and Cement due to handling, storage and transportation							1304713
7	Steel	Galvanised from ore	Kg	49170	7500		49170	25	1229250
8	Masonry	Fired clay (well fired bricks massive) 150 x 150 x 75	No	90940		2.5 Kg per piece	227350	3	682050
9	Tiles	Ceramic tiles (9-21 kg/sq.m.)	Sq m	2800	2000	12 kg / Sq m	33600	8	268800
10	Electrical conduit	Polyvinyl Chloride Pipe (dia 40 to 63 mm, wt 0.33 to 0.56 kg/m)	R m	3000		0.42 Kg / R m	1260	85	107100
11	Plumbing conduit	Polyvinyl Chloride Pipe (dia 40 to 110 mm, wt 0.33 to 1.64 kg/m)	R m	2000		0.78 Kg / R m	1560	85	132600

Table 7 – Estimated quantity of reused construction waste

Sr. no.	Waste material	Reuse practice	Unit	Total Waste	Unit	Total reused waste in 4 buildings – each building parking + 11 floors			Unit	Estimated quantity of waste material reused	Estimated energy involved in reused material in MJ
1	Tiles	Flooring of staircase landing at terrace level			Sq m	117			Sq m	117	
		Mosaic flooring design in front of entrance door of residential units			No.s	176	Sq m / design	2	Sq m	352	
		Top finish for sit out in the open space and entrance lobby			M		No.s	20	Sq m	15	
		Parapet top			M	603	Thickness	0.15	Sq m	90	
			Sq m	2800		Total			Sq m	574	55140
							Percentage			21	
2	Concrete	Use for lower grade concrete below open parking paving blocks			Sq m	470	M	0.30	Cu m	141	
		Plinth filling of club house			Sq m	84	M	0.45	Cu m	38	
		Bedding material below walkway in open space			Sq m	180	M	0.15	Cu m	27	
			Cu m	221		Total			Cu m	206	739978
							Percentage			93	
3	Steel	Steel bar 8mm, 10mm, 12mm for chairs, pins in beam (0.5%)						5% of total waste	Kg	2459	
		Steel bars length 4'0" to 6'0" for toilet slab, footing (0.5%)						5% of total waste	Kg	2459	
			Kg	49170		Total			Kg	4918	122925
							Percentage			10	

4	Mortar (Plaster)	Paver block bedding material (Parking and club house)			Sq m	6109				6109	
			Sq m	6985			Total		Sq m	6109	208942
							Percentage			88	
6	Brick	Coba filling / water proofing to terrace of residential unit (3 towers)			Sq m	110		11	Sq m	1214	
		Dry terrace			Sq m	35		11	Sq m	386	
		Water proofing for terrace slab			Sq m	1688					
		Filling below deck area							Sq m	435	
			Pieces	90940			Total			2035	
							36 Pieces / Sq m			73274	549558
							Percentage			81	
							Total embodied energy in Reused waste material				1676620
							Percentage				35

Table 8 – Estimated quantity of recycled construction waste

Sr. No	Waste material	Specification of material	Unit	Construction Waste	Waste in recycle				**Estimated quantity of waste material reused**	**Estimated energy involved in recycled material in MJ**
1	Steel	Galvanised from ore	Kg	49170	41792			Kg	41792	1044788
						Percentage			85%	
2	Electrical conduit	Polyvinyl Chloride Pipe (dia 40 to 63 mm, wt 0.33 to 0.56 kg/m)	R m	3000	2850	Kg/R m	0.42	Kg	1197	101745
							Percentage		95%	
3	Plumbing conduit	Polyvinyl Chloride Pipe (dia 40 to 110 mm, wt 0.33 to 1.64 kg/m)	R m	2000	1900	Kg/R m	0.78	Kg	1482	125970
							Percentage		95%	
							Total embodied energy in Recycled waste material			1272503
							Percentage			27%

Use of Energy-efficient Materials and Sustainable Design Strategy for Large Sports Architecture in Beijing

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ABSTRACT

The sports facility typically requires large open spaces and thus falls into the category of energy-intensive public architecture. The level of energy consumption directly reflects the operation cost of a large sports facility. The future role of architecture design will be critical to help improve energy efficiency by designing sustainably. Through the study of the use of energy-efficient materials in the design and construction phase, this article analyses the trend of using new energy-efficient materials in large sports architecture in Beijing, and discusses the key factors and techniques for selection of those materials. The impact of using energy-efficient materials on large sports architecture on its daily operation is also discussed. Lastly, it proposes a sustainable strategy for large sports architecture, from architectural design to the selection of energy-efficient materials.

INTRODUCTION

As civilizations have evolved, so does the world's need for energy. The question of how to balance economic growth with care for the environment largely revolves around energy. Countries, including China, face the challenge of meeting rising energy needs in ways that are cost-efficient, sustainable and environmentally compatible. Buildings are becoming the heaviest consumers of natural resources in China. The area of public buildings accounts for about a third of the total civil buildings, but they contribute to more than 50% of the total building energy consumption. High-performance green buildings do not represent just an environmentalist vision. They represent opportunities to reduce energy and operation costs.

As typical large public buildings, sports stadium and arena are energy intensive. They have the greatest energy-saving potential and are playing a key role to achieve China's energy conservation goals. After successfully hosting the 2008 Beijing Olympics, China has entered into the "post-Olympic era" as hosting large sports events and building sports complex are becoming "new normal". In the process of design and construction, owners are paying more and more attention to their daily operational needs. Energy efficiency is an important factor which influences the operational costs of large sports buildings.

China's Ministry of Construction has issued a regulation on civil building energy conservation, which prescribes that "Civil building energy conservation refers to the activities of reducing building energy consumption, reasonable and efficient use of energy in the process of the civil buildings' planning, designing, construction and use". As building energy conservation is a systems engineering, this paper mainly discusses the energy conservation and the sustainable development strategy for large sports buildings, from the perspectives of architectural design and energy efficient materials selection.

INTENT AND OBJECTIVES OF APPLIED RESEARCH

This applied research is based on the case study of the 2008 Beijing Olympic Games' competition and training venues. As a delegate of the State General Administration of Sports, author B has been participated in the construction process of the two projects that are analyzed in this paper, and is able to apply the project data in the study. Through the study of the use of energy-efficient materials in the design and construction phase, this article analyses the trend of using new energy-efficient materials in large sports architecture in China, and discusses the key factors and techniques for selection of those materials. The impact of using energy-efficient materials on large sports architecture on its daily operation is also discussed. Lastly, it proposes a sustainable strategy for large sports architecture, from architectural design to selection of energy-efficient materials.

PROCESSES

Beijing Sports University Training Center (Hereinafter referred as BSU Training Center)

Project overview. Beijing Sports University National Team Training Base was invested by the State General Administration of Sports in preparation for the 2008 Olympic Games. It was constructed as a comprehensive training base with the function of national team training, scientific research and education. As a training venue for the national teams, the BSU Training Center's gross floor area is about 29,700 m^2, with a total investment of about 206.6 million Yuan. It is 288 meter long, 72 meter wide and 24 meter high, and is one of the largest comprehensive training venues in China. The ground part of the whole building area is divided into three structural units: the west wing for track and field training center (axis plane size is 72m by 128m); intermediate for taekwondo hall and comprehensive auxiliary facilities (axis plane size 72m by 90m); the east wing for rhythmic gymnastics and trampoline comprehensive training venue (axis plane size 72m by 72m).

Table 1 BSU Training Center's use of energy-efficient materials

Building Part	Material Type	Construction Practice	Measured K Value*	Local Standards
Outer wall	Decorative insulation bearing integrated block	310mm thick insulation block, with 80mm thick polystyrene board insulation layer	0.45W/m^2 • K	0.6W/m^2 • K
Curtain wall	Broken bridge aluminum alloy glass curtain wall	Broken bridge aluminum alloy, low-e insulating glass, 12mm thick air space,6+12A+6	2.3W/m^2 • K	3.0W/m^2 • K
Roof	Multi-functional composite metal roofing	Metal roofing, fills in a 100mm thick glass cotton	0.5W/m^2 • K	0.55W/m^2 • K

***Overall Heat Transfer Coefficient of Building Envelope**

Energy-efficient building materials selection. The architectural design follows the "public building energy conservation design standard" (Beijing local standard DBJ01-621-621), which requires an energy saving level of 65%. It applies the approach of green, energy efficient and environmental friendly in the architectural design and material selection, reasonability designs the thermal performance of building envelope, and reduces building energy consumption. Its shape coefficient of building, overall heat transfer coefficient of building envelope and other indexes meet or exceed the standard limit, which lays a foundation to reduce the cost of daily operations for the venue. The main parts that use energy-efficient building materials include:

1. Energy-saving outer wall. The outer wall heat preservation, to comply with the standard of 65% energy saving, uses decorative insulation bearing integrated block. The size of the block is 310x190x90mm, with an 80-mm thick thermal insulation material for polystyrene insulation board inside. To prevent cracking, workers were required to strictly follow the construction procedures. The block wall's overall heat transfer coefficient of building envelope (K value) was designed as 0.45 W/ (m^2 • K). After a review by the specialized institutions upon the completion of the construction, the actual heat transfer coefficient is confirmed to be less than 0.6 W/ (m^2 • K), which meets the requirements of the standard of 65% energy saving.

2. Energy-saving windows and doors (curtain wall). The venue's glass curtain wall airtight performance is designed as class Ⅲ. The low-e insulating glass with a radiation rate of less than 0.25 was selected. The hollow glass curtain wall is equipped with a broken bridge aluminum alloy, double-layer, 6mm thick low-e glass and 12mm thick air space. All south to glass windows and glass curtain wall were installed with the set of infrared remote control electric sunshade inside. K value of the glass curtain wall is 2.3 W/ (m^2 • K).

3. Energy-saving roofing. The roofing of the venue uses the compound metal insulation board, filled with 100mm thick centrifugal glass cotton. The metal roofing system consists of a magnesium aluminum manganese alloy roof board, insulation,

lining layer, purlin and a sound-absorbing, galvanized steel base plate. K value of the metal roofing is 0.5 W/ (m^2 • K).

Beijing Shooting Range Hall

Project overview. Beijing Shooting Range Hall is the 2008 Olympic Games' shooting competition venue. It consists of a 10m air rifle hall, a 25m pistol pavilion, a 50m target pavilion, training and game rooms, technology rooms and supporting services, with a comprehensive function of training and competition. It serves as the national shooting team's training venue and a major competition venue. The gross floor area of the venue is 45,645 m^2, with a seating capacity of 9,000 audiences. The main structure of the venue is frame-shear wall structure, using the large-span space steel pipe rack and truss roof system.

Figure 1 Photo-realistic of BSU Training Center
Source: http://www.bsu.edu.cn

Figure 2 Photo-realistic of Beijing Shooting Range Hall
Source: http://lvyou.baidu.com/beijingshejiguan

Energy-efficient building materials selection. The architectural design performs the "public building energy conservation design standard" (Beijing local standard DBJ01-621-621), which requires an energy saving level of 65%. The venue design emphasizes the building functions, convenience & economy of use, leveraging the ecological building technology which is mature, reliable, and efficient. Through the use of architectural structure, detailed and appropriate building technology and materials, it enhances the overall quality of the construction. With the goal of being a green building, the venue used precast concrete heat preservation sound insulation wall panels, ecotype double breathing curtain wall, multi-functional composite metal roofing and other energy-saving new technologies. By using these typical energy-saving materials, it can effectively reduce the heat transfer coefficient of the building, and improve the overall thermal insulation performance.

1. Energy-saving outer wall. As a large sports facility, the Beijing Shooting Range Hall pursuits for an architectural style of simple natural atmosphere, as its facade emphasizes on large scale frame and deep seam decorative texture. It uses the outer walls of precast concrete heat preservation sound insulation wall panels, which are good for exterior wall thermal insulation, sound insulation, heat insulation, components and exterior decoration. As regards the construction technology, the first structure pendant was set aside for building structure, pasting 30mm thick extruded polystyrene insulation board on retaining wall surface, and hanging precast concrete wall panels outside. Hanging panels with insulation layer formed about 40mm air between the layers. The air layer is advantageous to the wall heat preservation and sound insulation, which greatly reduces the influence of indoor shooting training and competition to the external environment. At the same time, use of precast concrete heat preservation sound insulation wall panels can save the operational cost without more maintenance investment. By using the energy-saving outer wall system, the exterior wall heat transfer coefficient of the venue is greatly reduced. K value of the venue is significantly lower than the standard requirement of 0.6 W/ (m^2 • K).

2. Energy-saving windows and doors (curtain wall). When the venue was designed, it proposed a creative design of Ecotype double breathing curtain wall, considering the special requirements of sound insulation, viewing and energy saving. The curtain wall system is an externally circulating double curtain wall, with auxiliary external sunshade measures and intelligent control system, combining architectural shading, ventilation, ventilation function into an organic system. It also improves the construction technology for physical comfort. The inner glass wall uses 6 + 12A + 6 toughened hollow low-e glasses, and the outer is with 12-mm toughened glasses. The glass size is 1400 mm x 2500 mm. Calculation shows the ecological breathing curtain wall heat transfer coefficient has decreased to 1.3-1.5 W/m^2.K, which is much better than the public building energy efficiency standards and greatly reduces building energy consumption.

3. Energy-saving roofing. The Beijing Shooting Range Hall chose bem aluminum roofing system. Its metal roofing uses 0.9-mm thick aluminum manganese magnesium alloy plate, featured with light weight, high hardness and flexibility, corrosion resistant and maintenance-free. Roof construction bottom-up is ranged by: plate, aluminum foil, insulation cotton, purlin bracket, purlin, roofing and roof panel. Fire prevention, heat preservation cotton was adopted to achieve preferable centrifugal glass cotton insulation performance, and the thickness reaches 150 mm. By adding a layer at the bottom of the glass cotton insulation moisture-proof aluminum plus fascia, the roofing heat preservation performance is greatly improved. K value of the metal roofing is decreased to about 0.38 W/m^2, K.

Table 2 Beijing Shooting Range Hall's using of energy-efficient materials

Building Part	Material Type	Construction Practice	Measured K Value*	Local Standards
Outer wall	Precast concrete heat preservation sound insulation wall panels	Building structure reserve structure is hanged, retaining wall surface paste 30 mm thick extruded polystyrene insulation board, dry hanging outside of precast concrete wall panels, hangs panels with insulation layer formed between about 40mm air between the layers	<0.6W/m^2 • K	0.6W/m^2 • K
Curtain wall	Ecotype double breathing curtain wall	Inner wall of glass use 6 + 12A + 6 toughened hollow low-e glass, the outer with 12mm toughened glass	1.3-1.5W/m^2 • K	3.0W/m^2 • K
Roof	Multi-functional composite metal roofing	Metal roofing uses double metal plate, two layer board adopted the good fireproof and heat insulation performance between centrifugal glass wool, thickness of 150mm	0.38W/m^2 • K	0.55W/m^2 • K

***Overall Heat Transfer Coefficient of Building Envelope**

Survey of energy consumption in daily operations for the two venues

As a comprehensive training venue project, the Beijing sports university training center was completed by the end of 2007 in preparation for the Olympic Games in 2008.The Beijing Shooting Range Hall, which was completed in 2007, hosted the test event to stage the games in August 2007 and the Olympic Games official competition in 2008. The two venues are subordinate to the State Sport General Administration. The owners are respectively the Beijing Sports University and the Archery Shooting Sports Management Center under the State General Administration of Sports. After the 2008 Olympic Games, the two owners are responsible for the daily operations of the facilities. In this paper, the daily operational energy consumption levels of the two venues in 2008-2010 were investigated and analyzed. The comparative datas are from a research on quota of operation energy consumption for venues and accessory facilities by the State General Administration of Sports. The energy consumption values are set in accordance with the unified running time, which is 8 hours per day, 6 days per week(according to the training character of sports teams),and 12 months per year.

1. Electric power energy consumption spending

BSU Training Center's power energy consumption in 2008-2010 is 2643,300 kWh, 2651,913 kWh, and 2613,600 kWh respectively. The average annual electricity consumption of the venue is about 2.64 million kWh. Beijing Shooting Range Hall's power energy consumption in 2008-2010 is 2181,470 kWh, 2226,619 kWh and 2224,712 kWh respectively. The average annual electricity consumption of the venue is about 2.21 million kWh.

2. Energy consumption analysis

Training venues' energy consumption level is higher than the competition venues, due to the higher proportion of large space, and less accessory occupancy. Beijing Shooting Range Hall's annual power consumption in construction square meters is 48.4 kWh/m^2•a. BSU Training Center's annual power consumption in construction square meters is 88.9 kWh/m^2•a. Beijing Shooting Range Hall's annual heat/gas energy consumption in construction square meters is 21.3 m^3 / m^2•a. BSU Training Center's annual heat/gas energy consumption in construction square meters is 105.4 m^3 / m^2•a.

3. Comparison with the similar venues of the State General Administration of Sports

To analyze the energy saving performance, we choose some similar venues for comparison, which are subordinate to the

State Sport General Administration. The sample venues were all newly built or renovated for the 2008 Beijing Olympics, with the gross floor area of more than 20,000 m^2, and the highest ceiling height of more than 16 meters. We take the whole architecture as the research object, including the arena, stands and accessory functional rooms. The electric power energy consumption of BSU Training Center and Beijing Shooting Range Hall, are in the middle range of the group of similar venues, and both are lower than the quota standard set by the State Sport General Administration.

Table 3 Energy consumption comparison with the similar venues of the State General Administration of Sports (Excluding the heating energy consumption)

Item	Project Name	Average Electric power energy consumption (kWh / m^2•a)	Gross floor area(m^2)
Training venue (ceiling height more than 16 meters)	BSU Training Center	88.9	29700
	Comprehensive Training Venue of National Olympic Sports Center	69.6	27000
Competition venue (ceiling height more than 16 meters)	Beijing Shooting Range Hall	48.4	45645
	Laoshan Cycling Velodrome	102.0	38000
	National Olympic Sports Center Gymnasium	40.1	32410

From another perspective, we compare the two venues with the Sports and Cultural Center in Shenzhen Overseas Chinese Town, which is among the first buildings that have been certified as the National Three-Star Green Building. The compared building was built in Oct, 2008, with a gross floor area of 5130 m^2, and building height of 15 meters. The annual operation energy consumption intensity of the building is 50.35 kWh/(m^2 • a). Although the building scale of BSU Training Center and Beijing Shooting Range Hall is much larger than this green building, their operation energy consumption intensity is close.

4．Comparison with Chinese large public buildings' current energy consumption

According to a research of Building Energy Research Center of Tsinghua University in 2009, the Chinese large public buildings' current energy consumption are 70-300kWh/(m^2 • a) (excluding the heating energy consumption). The researched large public buildings are central air conditioning and having a building area of more than 20,000 m^2.

The Building Energy Research Center of Tsinghua University also suggested a reference energy consumption index for new-built large public buildings in Beijing in 2010. The index for public office buildings is 72 kWh/(m^2 • a). The index for business office buildings is 105 kWh/(m^2 • a). The index for hotels is 141 kWh/(m^2 • a). The index for large shopping mall is 210 kWh/(m^2 • a). However, they didn't give a suggestion for large sports buildings.

Compared with the above existing data, the energy consumption level of Beijing Shooting Range Hall and BSU training center is significantly lower than that of most of the large public buildings.

OUTCOMES

New trend in the application of energy-efficient building materials

Energy-efficient building materials refer to the building materials with low energy consumption in daily operations and in the process of building, by changing the nature of the materials to achieve the goal of building energy efficiency. The significance of applying energy-efficient materials is that while meeting the architectural space or the thermal environment of thermal equipment, it can help save the energy to a great extent. China is paying an increasing attention to the building energy efficiency and the implementation of corresponding energy saving standards and norms, and the rapid development of building energy saving materials. From the case study of Beijing Shooting Range Hall and BSU Training Center, we can find that the evolvement of applying a single energy saving material to the development of multifunctional composite materials and an energy saving system is becoming a new trend in the application of energy-saving materials. For example, the BSU Training Center's decorative insulation bearing integrated block, Beijing Shooting Range Hall's precast concrete heat preservation sound insulation wall panels etc, are all applying the composite materials to form a comprehensive system of energy conservation.

Key parts and techniques for selection of energy-efficient materials

For large sports architecture, the thermal performance of building surrounding structure is very important to the building's energy efficiency performance. According to the spatial characteristics of the large-scale sports building, the key parts of energy conservation and material selection are outer walls, doors and windows (curtain wall) and roofs. Key techniques are the integrated system structure, processing hot bridge and cold bridge, through improving the structure of heat preservation and insulation system to achieve good energy saving performance.

The energy saving performance

Both Beijing Shooting Range Hall and BSU Training Center are large sports buildings. Beijing Shooting Range Hall has a total length of 420 meters, while Beijing Sports University training center has a total length of 288 meters. Both venues are more than 20-meter high. Through using energy-efficient architectural design and materials in the key parts, the two venues achieved good energy saving performance, significantly lower than the energy consumption level of most of the large public buildings in Beijing. The venues are the models of the green Olympic buildings.

INFERENCES AND CONCLUSION

Sustainable architecture is a future trend. The energy conservation potential for large sports buildings is tremendous, so they should be guided under the energy efficient and environmentally friendly sustainable development strategy. The key is to implement sustainable architectural design methods and to select energy-efficient materials in the process of construction.

Sustainable building design

We should start the research from the angle of ecological sustainability, and achieve the goal of sports building energy saving, water saving and material saving design strategy, through the use of appropriate technology. Considering the domestic situations, we should work out a strategy of reducing total life cycle cost from three aspects: the initial cost, maintenance cost and update cost control. Based on principles of intensive construction, we can explore sports building design strategy of low cost and low loss which addresses the current situation of China.

Energy conservation and material selection

The main energy conservation goal of large sports building is to consume as less energy and resources as possible, in the meanwhile minimizing the impact on environment and ecology, and providing the users with a healthy and comfortable building environment. Choosing energy-saving materials in the process of design and construction, and implementing building energy efficiency standards, is an important approach to realize the energy conservation goals and promote the sustainable development concept of the large sports building. Through the reasonable design and selection of energy-efficient materials, we can gain great energy efficient performance in the long run in exchange of a smaller building cost increase at present.

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Performance of Phase Change Materials for Cooling of Buildings in Mild Climates

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ABSTR ACT

The effect of phase change material (PCM) integration in buildings is investigated in mild climates for the entirety of the hot season. The incorporation of PCMs in building materials is particularly interesting because it allows for the thermal storage to become a part of the building structure while being completely passive. Simulations in a typical single-family home are carried out, and the effect of incorporating PCMs in different building components is analyzed. Results show an important reduction in cooling energy.

1- INTRODUCTION

World electricity consumption is expected to double by 2025, increasing at a significant rate of 3.5 % per year. Furthermore, the demand for thermal comfort in both domestic and commercial buildings is currently rising. The additional energy demand significantly contributes to the increasing consumption with a peak demand in mild and hot climates. However, any action must start by reducing the level of energy consumption or at least delaying the peak demand.

To shift the peak energy demand (ideally few hours), the thermal mass of buildings can be used to store energy and lessen indoor temperature fluctuations. Nevertheless, the requirements of a thermally massive building often conflict with cost or aesthetics that require buildings to be increasingly lightweight. Incorporating phase change materials (PCMs) into buildings is a way to artificially increase the thermal mass of lightweight structures (Zhang et al, 2007). Heat storage can either take sensible or latent forms. Sensible storage is accomplished by increasing the temperature of the material, whereas latent heat storage is accomplished by changing the physical state of the material. To store the same quantity of energy, a smaller amount of material is required for latent storage. For example, a common building material, such as concrete can store about 1 kJ/kg when subject to a temperature increase of 1°C, whereas a PCM, such as calcium chloride hexahydrate can store/release up to 193 kJ/kg on complete phase transition (Kenneth and Gates, 2000). This huge increase of thermal storage capacity for PCMs and their almost isothermal discharge could be used to stabilize ambient temperatures inside buildings.

Currently, the available commercial micro-encapsulated PCMs are made with paraffin waxes embedded within small polymer spheres of about 10-20 μm in diameter. When in powder form, PCMs can be mixed directly into the building material or internal wallboard without risking leakage. The additional latent heat capacity for the distributed PCM increases the overall effective heat capacity when compared with sensible storage alone (Khudhair and Farid, 2004). The main advantage of setting a PCM in wallboards and incorporating it into the internal side of the external envelope of a building is to have a large surface in contact with the indoor air.

Recently, incorporating phase change materials (PCMs) in building materials to reduce the cooling needs has been investigated in many studies. An extensive literature review on micro encapsulated PCMs and the application in buildings can be found in (Osterman et al, 2012) or (Zhao and Zhang, 2011). However, these studies mainly address lightweight or reduced scale constructions (laboratory scale testing, (Tardieu et al, 2011). Therefore, the obtained results cannot be generalized and are inconclusive regarding the benefits in real buildings and climates. Indeed, the experience conditions for the reduced scale generally lead to a large day/night temperature variation, which allows the PCMs to swing widely around the melting temperature. In this case, charge and discharge cycles are fully accomplished, and in turn, PCMs are in their optimum working mode. However, when simulating a long period (all the hot season for example), it is the average values that must be considered. A PCM can perform badly on a particular day, but might still perform well on average for the whole season.

With this work, our aim is to see how PCMs can reduce thermal loads in real buildings and how they can decrease fluctuation of indoor temperature to improve summer thermal comfort. Additionally, we will try to see if a unique optimum switch temperature exists and what parameters influence this temperature.

2- MATHEMATICAL MODEL

For the mathematical modeling, a nodal method was used. With nodal methods, a system is decomposed into isothermal (but not necessarily elementary) volumes. Each volume Vi is represented by a node with calorific capacity $C_i=\rho_i Cp_i V_i$. The heat exchange of a node with its neighbors is represented by thermal conductances (opposite to thermal resistances) characterizing different modes of heat transfer (conductive, convective, radiative and “fluid”). The energy conservation equation at node i connected to its neighboring nodes j and with a heat source $Q_i(t)$ is as follows:

$$C_i T'_i = C_i \frac{dT_i}{dt} = \sum_i G^c_{ij}\left(T_j - T_i\right) + \sum_k G^r_{ik}\left(T_k - T_i\right) + Q_i(t) \qquad (1)$$

G^c_{ij} and G^r_{ik} are conductive (or convective) coupling conductance and radiative conductance, respectively. When applied to all nodes, the energy conservation equation leads to a set of nonlinear, yet ordinary algebraic-differential equations. A dynamic solver is then used for the transient resolution. This type of method provides a very powerful tool for modeling complex systems with heterogeneous interactions, such as a building, and the precision is within the limit of validity of the isothermal assumption of the chosen nodes. In our case, the main advantage of those methods is the ability to consider the wallboard as an isothermal single node and then not necessarily solve the melting front position. The modeling of latent heat change use only its effective capacity C_{ef} , which is temperature dependant. It is treated as non-linear, such as others temperature dependant physical properties or conductances (natural convection or radiation for example). The actual solvers are robust and can deal with the very sharp evolution of C_{ef}.

The encapsulated PCMs are particularly candidates for this type of modeling because they are randomly mixed with gypsum to form a homogeneous material. The heat capacity is the sum of the capacities of the constituents (sensible and latent) as shown by (Shukla et al, 2012) and the density is the weighted average of densities.

3- PCM CHARACTERIZATION

Among key parameters for PCM simulation, thermal properties such as switch temperature and the enthalpy variation with temperature of are of primary importance. From the enthalpy variation h=f(T), which can be determined by several methods, such as Differential Scanning Calorimetry (DSC) or T-history, the effective capacity, C_{ef}=f(T) is a follows:

$$C_{ef} = \frac{\partial h(T)}{\partial T} \tag{2}$$

Because the model takes into account the phase change by the variation of the heat capacity during the phase transition, it is necessary to know its explicit variation versus temperature. There are several representations for this variation of C_{ef}. (Feustel, 1995) gave a simplified representation with an exponential symmetrical shape:

$$C_{ef} = C_{sl} + \frac{\Delta H}{2} \frac{2\beta / \tau}{Cosh^2\left[\frac{2\beta}{\tau}(T - T_m)\right]} \tag{3}$$

Where C_{sl} is the liquid phase heat capacity; ΔH the fusion latent enthalpy and T_m is the melting temperature (or switch temperature), β is a shape parameter and 2τ is a range where 99% of the phase change occurs (melting or freezing). The solid-solid peak transition is neglected because the temperature is not relevant for the wall's operating temperature. The representation is also using equal capacity values for liquid and solid phases. No hysteresis was also assumed between melting and freezing, which is generally the case with organic PCMs. In fact, in our calculations, a slight hysteresis (a shift of approximately 1°C) had practically no effect on long-term simulation if the switch temperatures are close to the optimum values.

Different values for the conductivity of gypsum with PCMs are found in the literature ranging from 0.15 W/mK to 0.6 W/mK mainly because different conductivities of the gypsum matrix are reported. A conductivity of 0.3 W/mK is considered for this work and the change of phase of the PCM do not have a substantial influence on thermal conductivity of the wallboard (Jaworski and Abeid, 2011).

4- THE CASE STUDY MODEL

Among numerous factors that influence energy consumption and performance of buildings with PCM integration, the following main parameters are identified:

- Local construction systems (envelope and windows).
- Local climate: solar irradiation and ambient outdoor temperature.
- Internal loads: the personal occupancy and electrical appliances (lights, TV, computers, etc.).

The case study involves a typical residential single-family house with an area of approximately 104 m^2 area, two bedrooms, one living room, one kitchen, one bathroom and one storage room.

Two windows (simple glass U=4.4 W/m^{2}K) are located in the north and south walls and the window-wall ratio (WWR) is approximately 12% (see figure 1 for the sketch). The constructive system is typical of the Mediterranean countries with a relatively heavy envelope (solid concrete end-terrace roof and measonery brick walls). Windows are shaded is by roof eaves and shutters (shading factor fs=0.5) in the summertime and the solar absorptivity is assumed 0.5 for the roof and the walls.

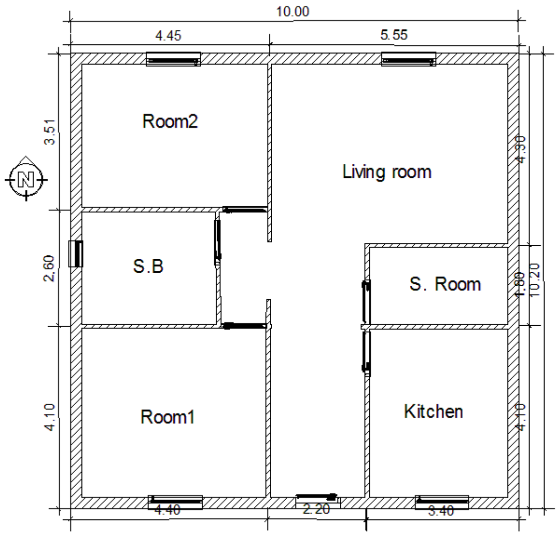

Fig 1. Sketch of the building model.

Exterior walls are traditional double brick walls with a 5 cm air gap (see table 1 for thermal characteristics of building components). The levels of insulation seem to be lower compared to those in continental climates, but they are sufficient for the Mediterranean region. PCM (when being present) of varied switch temperature between 24°C and 32°C is embedded in the wallboard of gypsum plaster of 15 mm nominal thickness. They contain between 0% (no PCM) and 30% mass fraction of encapsulated paraffin and are set into the internal face of the walls or the ceiling.

Table 1. Thermal characteristics of the building components.

	Roof	**Ext. Wall**	**Floor**	**Glass**
U-value [W/m^{2}K]	1.26	1.23	2.41	4.40

The study is carried out for the city of Djelfa, Algeria a typical Mediterranean city with a sub-continental climate: a mild-warm climate and relatively hot and dry summer. When the indoor temperature exceeds 26°C, cooling is activated and split system room air conditioners with 100 W/m^2 power are used. Thermal loads for occupancy and appliances are omitted to obtain a non perturbed comparison for PCM efficiency. For the same reason, only the absolute indoor temperature (and not operative or adaptive temperatures) is considered. The internal convection coefficient is difficult to determine because deviations of more than 100% can be found in the literature (David et al 2011). In this study, h=8.3 W/m^{2}C is used for vertical walls (according to ASHRAE recommendations, Diaconu and Cruceru, 2010) and h=3 W/m^{2}C for ceilings (stratified hot air on top) as average values for combined transfer coefficients (convective and radiative).

5- RESULTS AND DISCUSSION

The year round cooling performances of a PCM are evaluated. However, only the summer period is considered, i.e., June, July, August and September (the period from June 1st to September 30 is also generally the period where the differentiated electricity price for on peak and off-peak period exist in many countries). Two very simple indicators are used.

The first indicator is for a passive house (free cooling without air conditioning) with a "discomfort index" I_{sum} (Zhang et al 2007, modified by scaling it for the considered period):

$$I_{sum} = \frac{\int_{season} (T_{in} - T_{set})\, dt}{Season} \qquad \text{when } T_{in} > T_{set} \qquad (4)$$

This indicator shows how long (and how much higher) the indoor temperature is above the comfort temperature, which is assumed to be 26°C (overheating). The second indicator is for an air-conditioned house and shows the primary energy demand Q_c, or the quantity of primary energy that needs to be removed from the indoor building by an active cooling system to confine the indoor air temperature to a maximum of T_{set}=26°C.

$$Q_c = \int_{season} q_c dt \qquad (5)$$

Figure 2a shows the indoor temperature with a 30% PCM fraction weight and T_m=25°C and figure 2b shows T_m=27°C (ΔH=160 kJ/kg). From those figures, we can see that for T_m=25°C, the PCM performs well early in the hot season in June and in late September, but less so in the middle of the hot season (the hottest days). With T_m=27°C, the PCM seems to work mainly in the middle of the hot season (July and August). The adjustment of the switch temperature permits to control of which days of the hot season are concerned by PCM action.

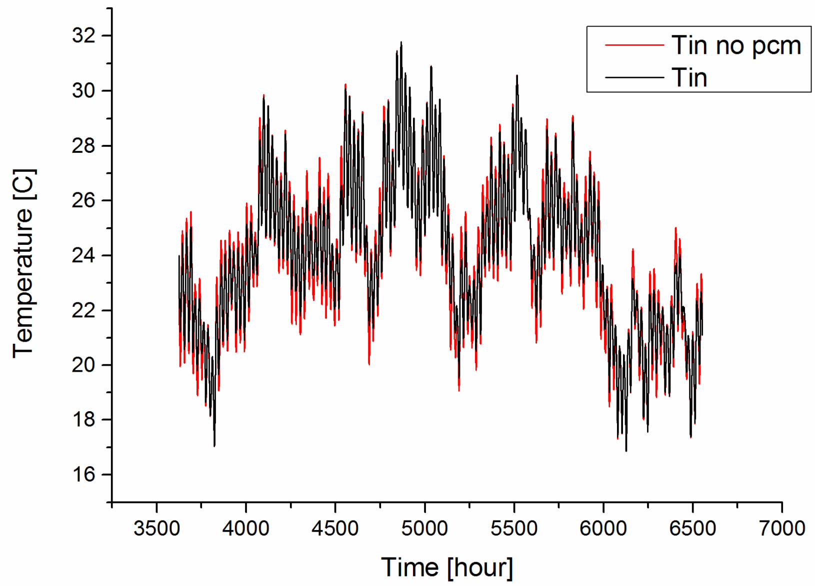

Fig 2a. Evolution of the indoor temperature without and with PCM, T_m=25°C.

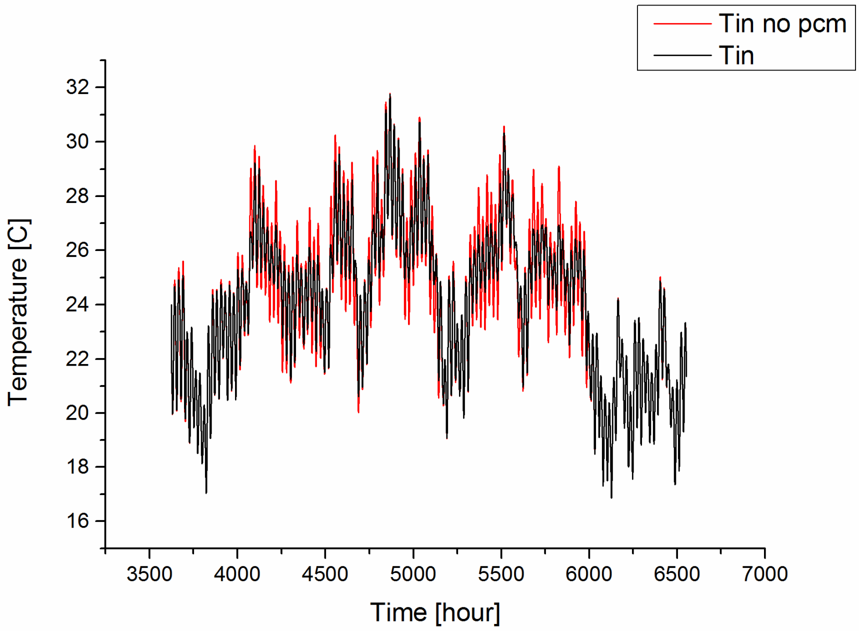

Fig 2b. Evolution of the indoor temperature without and with PCM, T_m=27°C.

Table 2 shows the discomfort index Isum and the cooling load Q_c for a PCM set on the internal face of walls and the ceiling for different switch temperatures and for a PCM fraction weight of 30% and with T_{set}=26°C. It is clear with those two indicators that the optimum switch temperature is between 26 and 27°C. However, a switch temperature close to this range would provide slightly different results. The maximum reduction on cold demand with the incorporation of PCMs is about 20% which is in the average of results found by the others studies.

Table 2. Discomfort index and cooling load variation with switch temperature T_m (W_t=30%, τ=3)

	No PCM	T_m=25°C	T_m=26°C	T_m=26.5°C	T_m=27°C	T_m=28°C	T_m=29°C
I_{sum}	0.642	0.557	0.524	0.514	0.508	0.514	0.530
Q_c [kWh]	1384.01	1171.36	1111.24	1106.50	1118.07	1160.02	1175.85

It is interesting to see if this optimum switch temperature is the same for both components (walls and ceiling). Table 3 shows the two indicators with PCM only set on the walls and Table 4 shows those with PCM only set on the ceiling (internal face). The results show that the optimum switch temperature is approximately 26°C for the walls and approximately 31°C for the ceiling. This is because the walls and the roof do not receive the same amount of solar irradiation and consequently, do not operate at the same temperature.

Table 3. Discomfort index and cooling load variation with switch temperature T_m PCM set on the walls (W_t=30%, τ=3)

	No PCM	T_m=25°C	T_m=26°C	T_m=27°C	T_m=28°C
I_{sum}	0.642	0.560	0.530	0.529	0.555
Q_c [kWh]	1384.01	1178.17	1127.06	1172.42	1282.25

Table 4. Discomfort index and cooling load variation with switch temperature T_m PCM set on the ceiling (W_t=30%, τ=3)

	No PCM	T_m=28°C	T_m=29°C	T_m=30°C	T_m=31°C	T_m=32°C
I_{sum}	0.642	0.591	0.571	0.556	0.553	0.562
Q_c[kWh]	1384.01	1258.00	1201.59	1161.31	1154.00	1178.75

Note that even if the areas (and then the PCM quantities used) for the ceiling and the walls are equivalent (102 m^2 and 113m^2, respectively) and the received irradiation is different, the PCM perform in the same way (16.5% and 18.5% in reduction of the cooling demand, respectively). In fact, the ceiling receives more solar irradiation than external walls but has in revenge a weak convection heat transfer coefficient compared to the walls.

6- CONCLUSION

The incorporation of encapsulated PCMs in building materials such as gypsum wallboards was investigated for the entirety of the hot season to reduce cooling energy or enhance thermal comfort. The PCMs are found to perform well a reduction of approximately 20% for cooling energy. This PCMs performance is realized even in mild climates characterized by low day/night temperature swings, which make night time ventilation less efficient for discharging the PCM. Anyway, the reduction of the cooling energy is obtained with relative large quantity of PCM. A local economic efficiency analysis must confirm the process profitability.

The PCMs have better performance on surfaces that undergo the widest temperature variation. Incorporating PCMs on the ceiling give the best compromise gain/cost and is relatively easy to realize even in existing houses. This shows their potential use for refurbishment of actual buildings which is the weak point of all energy conservation policies.

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Exploring New Methods of Constructing Houses with Sustainable Materials in Rural Bangladesh

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ABSTRACT

The paper investigates methods of house construction using organic materials in the rural areas of Bangladesh. Historically, people of Bengal have built their houses with natural and sustainable materials like mud, thatch and bamboo. However, the sustainable and vernacular tradition of homesteads went through major transition in the last century and the natural materials have been replaced with non-organic and energy inefficient materials like CI sheet, oven-baked brick and cement. Moreover, wood, a very scarce material in Bangladesh is widely used for doors, windows and roof structure. Research shows that these materials contribute to pollution, deforestation and depletion of fertile top soil. To tackle these challenges, different materials and techniques were implemented in building houses in the northern Bangladesh. The paper discusses the new method which eliminates CI sheet, wood and baked brick from construction process and instead implements compressed earth blocks, jute based tin roof and processed bamboo. Some of these cost effective construction techniques have already been practiced over the years in the rural areas of Brazil, Columbia and India with positive impact. This paper through a series of examples, discusses these new construction methods implemented in rural Bangladesh which directly contributes to reducing carbon emission and decreasing of deforestation.

INTRODUCTION

The paper discusses new methods and materials of constructing rural houses using compressed earth block (CEB), Jute Composite Tin (JCT) and bamboo. A two storied clinic was built using the new methods in the remote area of Bangladesh. Using this clinic as a case study, the paper discusses techniques, research findings and outcome of the construction method.

There are over hundred million people inhibiting rural areas of Bangladesh. Most of the country is low lying flat land with numerous rivers crisscrossing the plane. Historically, people of Bengal delta have built houses with natural and sustainable materials like mud, thatch and bamboo. The process has changed significantly over the last half a century and now the major materials used to build houses are CI sheet, Kiln baked brick, cement and wood. At present over 8000 brick factories produce nearly eight million tons of carbon emission every year. Corrugated iron industry adds another six million tons of CO_2 in the air. Generally the house owners, local masons and small contractors play significant role in the construction process in the rural areas. For most of them material choices are scarce and expensive. A corrugated iron sheet house has little or no insulation and contributes to poor housing situation. The new method of construction aims to handle these challenges.

INTENT AND OBJECTIVES OF APPLIED RESEARCH:

The objective of the project was to acquire knowledge in the new construction method and to find out if the new construction method can be socially and economically viable for the rural architecture of Bangladesh. Instead of using kiln fried bricks, the intent was to use CEB and measure its impact. Moreover, Jute Composite Tin (JCT) was used instead of Corrugated Iron sheet to measure the technical and environmental impact. Cured bamboo was used in constructing the second floor to minimize the static load. Also, implementing cross bracing and other construction technique, the longevity and the strength of the building was measured. Finally, the environmental impact of earth, jute and bamboo as construction materials were observed compared to current models.

Figure 1 *A clinic in rural Bangladesh built with Earth, Bamboo and Jute*

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CONSTRUCTION APPROACH:

COMPRESSED EARTH BLOCKS (CEB)

A small mobile unit of CEB machine was installed on site to produce the bricks. The machine was locally produced from free source design material available on the internet. The machine produced on an average 1000 bricks per day. The main ingredients for the bricks were 5% cement, 40 -50% sand and 50 - 55% earth. Although, the technique for brick production was taken from proven methods of UNHABITAT and GTZ, various experiments were performed at the beginning to get the most durable and strong bricks.

Figure 2: *Brick Machine is used to produce CEB which are 1.5 times bigger than regular bricks.*

TREATED BAMBOO:

The bamboo used in the project was cured thoroughly. The bamboo was submerged in water and a small amount of borax for 21 days and dried in shade for another 7 days. The curing process resists the bamboo from termite infection. Moreover, once the project was finished, a coat of varnish was applied for longevity.

The bricks were placed without mortar, but every three feet, 3mm iron rods were placed to hold the bricks. Afterwards mortar slurry was inserted into the aligned holes. The fusion of mortar slurry and iron rods created strong internal columns to bind the whole structure.

Figure 4 *Construction process of the rural architecture of Bangladesh using new construction method.*

JUTE COMPOSITE TIN (JCT):

Using jute, resin and crystalizing agents, Jute composite tins were developed for the roofing material. Jute composite could be molded into any form of tiles. However, since rural masons are trained at making roofs with CI sheets, the same forms were replicated. Countless experiments were done with various proportions of resin and crystalizing agents. Moreover, various kinds of jutes with different thread counts and density were experimented to find out which one produced the strongest JCT. Finally, a superior quality JCT was achieved that is more strong and durable than regular CI sheet.

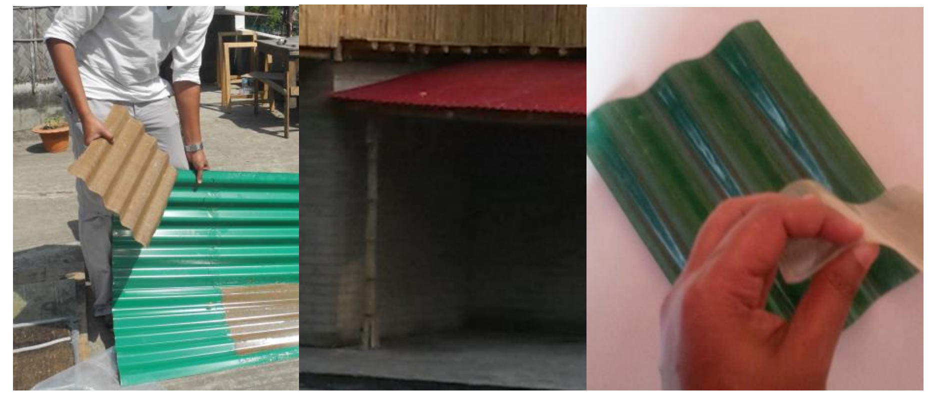

Figure 3*: Jute Composite Tin (JCT) made from jute, resin and crystalizing agents.*

SOCIAL APPROACH TO NEW CONSTRUCTION METHODS:

It is of course always a challenge to introduce a new method in the market, regardless of how good it is. Strong mindset about existing construction methods are hard to alter and new materials often fail to gain trust. Moreover, people do not want to take risks with their savings in new and unproven things. However, cost is a big factor in the rural areas of Bangladesh. People are attracted to cheaper yet better material. Once we finished constructing a 10’ x 20’ house with CEB in less than two weeks and in much cheaper price, high interest was generated among the villagers. The newly designed house built with earth, bamboo and jute looked more attractive and was much comfortable than a ci sheet house. In economy of scale, once the CEB and JCT will be mass produced, the cost of the house will also come down significantly.

	CI Sheet House	**Brick House**	**Earth – Jute House**
COMPARATIVE STUDY OF CONSTRUCTION METHODS IN RURAL AREA ON A 10’ X 20’ MODEL.			
Cost (100taka = 1Euro)	200,000 – 300,000 taka	500,000 – 1,000,000 taka	150,000 – 200,000 taka
Materials	CI Sheet, Iron, Wood, Cement	Kiln fried brick, cement, iron rods, concrete, wood, etc.	Earth blocks, cement, Jute Composite Tin, bamboo
Insulation	Very minimal insulation	High insulation	High insulation
Construction time	4 to 6 weeks	6 to 12 weeks	2 to 4 weeks
Comfort level	Low	Low to medium	Medium to high.

RESEARCH FINDINGS

Jute Composite Tin (JCT) was superior to Corrugated Iron (CI) Sheet in almost all the test. JCT is more durable than CI and GP sheets. Because of the properties of jute and resin, much higher heat insulation was achieved. The JCT is rust proof and contains no toxic materials like lead or sulfur. Since there is no iron involved it is completely saline water resistant. Sound proofing is higher and it has very low thermal expansion

	Corrugated Iron Sheet (CI SHEET)	Jute Composite Tin (JCT)
Cost (100 taka = 1 EURO)	5000 – 20000 taka per baan	10,000 taka per baan (*1 baan = 180 sq. feet)
Saline resistance	Subject to corrosion	Corrosion proof
Toxic material	Lead, Sulfur, Galvanizing material, corrosive iron etc.	Resin.
Heat required to produce 1 baan	600 – 700 degrees F.	No heat required.
Insulation and comfort level	Very low.	High

Compressed Earth Blocks (CEB) has been around for a long time and many researches have been done to show its superior quality over regular kiln fired bricks. In this particular project, we concentrated on environmental impact, insulation and usability.

The table shows the comfort index of users inside the building compared to the existing brick cement houses. Y axis represents air temperature while X axis represents hours during the day.

	Regular Kiln fired Bricks	Compressed Earth Blocks
Cost (100 taka = 1 EURO)	7 – 10 taka per piece	5-7 taka per piece (based on 1000 bricks per day)
Water resistant:	Yes	Yes
Environmental impact:	8 million tons of carbon emission in Bangladesh every year	Very minimal. CEB's are made with 5% cement stabilization, therefore carbon emission of cement should be considered
Heat required to produce 1000 bricks	1000 – 1500 degrees F	No heat required.
Mortar requirement :	Mortar cement is required for laying bricks and wall plastering	Mortar is only required to make internal columns
RCC Columns requirement:	Columns required every 10 – 15 feet for brick filling	No columns required. Walls are load bearing and internal columns are inserted through the bricks.

Cured bamboo was used instead of regular bamboo to extend the longevity of the building. If the cured bamboo is not found locally, it can be cured with minimal effort. The cost of curing needs to be added with the individual bamboo cost. The selected findings are given below.

	Regular bamboo	Cured bamboo
Cost (100 taka = 1 EURO)	100-150 taka per piece	170-200 taka per piece
Termite resistance	No termite resistance.	Termite resistance.
Availability	Widely available	Not widely available.
Processing time	Can be used directly after cutting	Need to cure for at least 3-4 weeks
Longevity	3- 10 years depending on annual perspiration.	20 – 50 years depending on maintenance

INFERENCES AND CONCLUSION

This particular type of material and construction techniques has a huge potential in rural Bangladesh. Furthermore, carbon emission is significantly reduced in the new method, resulting in a very positive environmental impact. Since the labor cost is cheap in Bangladesh, Compressed Earth Blocks (CEB) can be produced in large scale and in much more cost effective ways. As a result, the price of house will be significantly lower and more for the rural people. The CEB machine requires investment at the beginning. However, this also has potential to create local entrepreneurs. Moreover once the new methods enter mainstream construction, more masons and entrepreneurs will be interested to build with these bricks. Jute Composite Tin on the other hand will have rather big challenge to penetrate the market because of its high price. However, since it is rust proof and once the economies of scale will be achieved in mass production, it will have a significant advantage in the coastal areas where corrosion of regular CI sheet is a major problem.

ACKNOWLEDGMENTS

Eza Chowdhury, the client extraordinaire, who took a leap of faith and allowed her clinic to be made with experimental sustainable materials. 'Gold of Bengal' and Walid Ahmed assisted with jute materials and research data. Apu Roy with his team of bamboo workers from Dinajpur and Azoffor with his team of local masons from Faridpur worked tirelessly on the ground. The workers featured in the first page picture, not only built the clinic in shortest possible time, but also made significant contribution to data collection and research findings. Junior Architect Abir, Anwar and Sifat assisted in documentation. Lastly my wife Aurelie Rob, whose understanding, support and encouragement was vital for me to complete this research.

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Proposal of a Methodology for the Architectural Design of Timber Houses

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ABSTR ACT

This paper presents the principles of a method for the architectural design of timber houses based on the experience gained by timber companies. This proposal has as its major goal the challenging of the scenario of countries like Portugal where a shift in the design and construction methods integrating wood as a material could result in a much more sustainable habitat. A set of interviews was carried out with Portuguese companies in the sector of timber houses. They were questioned about their customers, design methods, the architect's role and the choice of structural systems. Based on the interviews it was possible to characterize the market and identify the main procedures about design. The most relevant ones were the importance of the architectural type definition, the support of a catalog, the relationship between formal and structural types and the architect's lack of knowledge about timber. The collected information pointed to an architectural design method to be used by Portuguese architects who, until now have often played a secondary role when a timber house was designed partly because the timber companies dominate the whole process. Some of these companies offer catalogues of design solutions that support customer's choices. The architects generally reject this type of method because of its supposed uncreative and impersonal results. The method here presented through some basic principles aims at collecting some positive lessons from the catalogue method, defining a process based on the recognition of Formal types and Construction types. This is the framework of a tool intended to help the Portuguese architects to deal with the range of the options available (solutions, companies, structural systems) and a support to help in deciding which construction system to choose.

INTRODUCTION

The adoption by architects of an architectural design method based on the information provided by the experience of timber house companies could lead to an increase in the use of timber houses. The replacement of Portuguese current concrete houses would originate several environmental benefits. The sustainable use of wood in single-family houses has been the subject of studies which conclude that there are advantages in its use over conventional solutions such as reinforced concrete (Monahan & Powell, 2011; Monteiro & Freire, 2012) and even over competing systems, such as light steel framing (Bolin & Smith, 2011; Rabbit, White, & Gervais, 2012). It is argued that the replacement of wood construction materials could result in a reduction of carbon emissions (Sathre & O'Connor, 2010). Even recognizing that there is no consensus on the results of such studies (Coelho, 2012; Gervasio, 2013) there are other arguments to consider when dealing with timber construction: the construction time and the prefabrication level. The average construction time for the current single-family houses in 2012 was 25 months (INE, 2013) while the construction time for wooden houses in Portugal is less than 6 months (Morgado & Pedro, 2011).

Although Portugal has a forest richness that could, with a growth in domestic demand, provide some of the raw material for construction (Marques Morgado, 2012; Machado, 2004), the old tradition of building some house elements such as roofs, floors and some walls with wood was lost. But in the final of the 20th century the scenario began to change with the appearance of pioneer timber house construction companies. Usually the whole design process was managed by these companies almost without the advice of architects. Besides, until recently structural wood was not considered by Portuguese architects as a solution. Today their growing interest by timber houses can be observed through three situations: 1) the presence of timber construction companies that integrate architects or are managed by them; 2) the emergence of a small number of architects who become specialized in timber construction; and 3) the proliferation of commercial or academic proposals for modular house designs in timber, with high impact on the architectural community, but with reduced reception from the real housing market. Moreover, the single-family house is one of the most important works of Portuguese architects (Domp, 2014). This way the architects, required by law to design a house (Law n. º 31/2009), are very well positioned to inform their clients about the possibility of building with wood. Additionally, houses in Portugal are one of the most significant types of the building housing stock: 13.500 houses were built in 2012 against 1.212 apartment buildings (INE, 2013). However the architects' current design method may not be appropriate to timber house design. So this work does not focus on specific house solutions to reduce energy or to improve carbon sequestration. Instead of this it proposes a general method to allow architects to put into practice a more sustainable type of construction using wood, replacing the common practice of choosing by default concrete and brick.

Objectives and methodology

The objectives of this article are:

1) To provide a summary of the results of 15 interviews with Portuguese timber house companies;
2) To propose the principles of a design method based on some aspects of companies' experience;
3) To identify the relevant typological principles connected with timber construction in Portugal;
4) To identify the main issues to integrate in design procedures;
5) To identify the relevant criteria for choosing a timber structure from the set of various solutions.

The current work involved:

1) The review of related literature and continuity with the research already carried out by the authors (Morgado, Guedes, Ferreira, Cruz, 2013; Morgado, Guedes, Ferreira, Cruz, 2012);
2) Interviews with managers, technicians or sales technicians;
3) Analysis of the interviews;
4) The proposal of a method to support architectural design through its basic principles.

Initially 25 companies were pre-selected and contacted, because they were among better well-known companies in the Portuguese market or represented the diversity of the national reality. Because of this, companies that do not refer the product "House" in their advertisements, or those whose structure seemed to be very fragile or only with a very short period of activity have not been considered. From the group of selected companies, 15 were interviewed with predefined questions and 10 showed no availability to answer. The interviews took place between April 10 and May 8, 2014, having been made in most cases in the headquarters of each company. Only in one case the interview was conducted using a form filled online.

The interviewed persons were: ten managers, two design technicians and three sales technicians. The headquarters of these companies are located in a vast territory extending 380 kilometres of the Portuguese coastline (up to about 60 km east inland) from Vila Nova de Cerveira (north) to Setubal (south). Timber houses account for over 80% of the workload of seven of the interviewed companies, while in the other eight there is a variation between 5% and 55% of their area of activity.

The interviews were supported by a questionnaire with eight main groups of questions: 1) Companies information; 2) Clients; 3) Construction Process; 4) Conception and design; 5) Role of the architect; 6) Choice of structural systems; 7) Structural systems' features; 8) Design method. The interview will be analysed as a whole in another publication, so only the relevant questions for the goals of this paper will be considered.

THE INTERVIEWS

In the context of design methodology, national companies were classified based on the following criteria: the level of integration of the architect's activity, the number of building systems offered and the main companies' activity. Thus seven companies regularly work with architects, four occasionally work with them and the other four cover a market in which the activity of the architect is residual. Regarding the number of structural systems available for clients to choose from, seven companies offer three or more systems, four companies have only two systems and the other four companies emerge with just one structural system. All companies include design and construction activities (inside the company or with external partners) and five of them do not manufacture their products, as they are just partners of foreign factories.

Construction systems

The dominant building systems are light timber-frame panels and post-and-beam, offered by eight companies and also the log construction present in six companies. With only three answers each system, appear cross laminated timber (CLT), light timber frame, plank and columns, three-dimensional modules and heavy mixed systems are present in three companies. Four companies offer heavy mixed systems (post-and-beam with light timber frame, planks or logs). The preferred system of most companies is the light timber-frame panels with four choices, followed by post-and-beam with three choices and cross laminated timber, light timber frame and heavy mixed systems with two choices.

Clients

From the point of view of the interviewed companies, the arguments that lead a customer to choose a timber house are the Comfort (ten answers "very important" and four "important"), followed by the special architectural Aesthetics associated with wood (seven "very important" and six "important") and the Speed of construction process (five "very important" and ten "important"). The Environmental factors (three "very important" and five "important") and economics (three "very important" four "important") are less consensual. Regarding the type of agents who contact those companies, the final consumers are the most frequent, followed by architects. Most companies say that customers who approach them had already decided to build in wood. However the contacts are usually made in order to get a quote to compare with quotes those clients already have from other companies.

Construction process

The most common construction process consists in the prefabrication of components regarding the specific settings of each project (twelve answers "often" and one "occasionally") and it is also common to use prefabricated market standard elements (five answers "often" and nine "occasionally"). However, the onsite manufacture with reduced prefabrication is still considered cost-effective by some companies (four answers "often" and three "occasionally"). Some companies work with complete modules (three answers "often" and three "occasionally") or partial modules. All companies considered that distance is not a limiting factor of the project's viability, although it may increase the final work cost. The final prices quoted by companies for a wooden house ranges from about € 500/m2 up to € 1000/m2. The average price indicated by the 15 companies is about € 800/m2.

Method and design conception

Most companies (with one exception) consider, among other possibilities, the timber house design as a completely custom solution. All companies include a showcase of solutions available for client consultation, functioning in some cases as "catalogues of solutions" or books of patterns. This is a common device in the companies activity, whether based on pre-defined solutions (eleven responses), or based on a customisable modular system (six responses). The companies with a larger production of houses tend to offer a detailed catalogue presenting different types of solutions grouped in families of "styles" and structural types. Only two companies declared not to provide such a device, coinciding with situations where timber houses are a secondary activity. Among companies using the catalogue of solutions, only two considered it to be "less important", with the others considering that it is "very important" (five responses) or "important" (six responses).

The purpose of the "catalogue of solutions" is for most companies (seven responses) a reference to support customer choices, with only two companies considering that the catalogue offer products that customers actually accept and buy without any changes. Four companies considered that catalogues work more as a marketing medium. It was noticeable that several companies use their already built houses or their exhibition prototypes as models that act also as a "catalogue". When addressing the companies, most customers already have a pre-set idea of the functional type of house they want to build (twelve responses), but are often less informed about the symbolic type (language, proportions, details, finishes) and it is frequent that they are not enough aware about structural type definitions. Although with less answers, the client without predefined ideas also consults the companies for the support of the design services from early stages (two answers "often", nine "occasionally"). Architects, as expected, consult those companies with more defined ideas about functional and symbolic solutions, although not often with pre-defined ideas of the structural types. Companies use the pre-defined customer ideas as a starting point, although some minor adjustments (fourteen responses) are always required. When customers do not have pre-set ideas the most widely used process is the customization of solutions based on the catalogue (eight responses) and the definition of completely customized solutions process.

The architect's role

All companies offer architectural design, structural engineering and the other engineering services. However seven of them hire external architecture services and other seven hire external structural engineering services. The intervention of architects, in addition to the design development phase for authorities' approval, is generally lower in the phase of construction documents and in the coordination tasks. It should be noted that normally, in cases where the architectural services are hired by the client, the company prepares a set of documents to be reviewed by the architect responsible for the design approval. Regarding the knowledge of timber construction specificities, the architect is seen by companies as a professional who demonstrates "many difficulties" (seven responses) or "some difficulties" (seven responses). The most highlighted aspects were the difficulties about durability constraints (eight responses "many difficulties" and five "some difficulties"). The structural and hygrometric behaviour of wood and the construction details were also highlighted, although not with so much importance. It may be added that one of the interviewees considered that cases where the architect's solutions fail are explained by the importing of architectural models from central and northern Europe, whose performance in the national climate (thermal and humidity conditions), turn out to be deficient. The architect is nevertheless considered an important partner, as expected, for the completion of approval designs, the implementation of the program and the definition of formal solutions. Questioned about whether the intervention of the architect leads to more complex, more expensive, or later problems, most companies found that that it does not affect the normality of the work, although some companies indicated negative responses and no company indicated that the architect's intervention has a positive effect on these parameters. Five companies answered that architects are responsible for more complex processes, four mentioned higher costs and three mentioned later problems. Most companies defend that the structural engineering must be integrated in the company (eight responses), opposite to a minority (four responses) that consider that it should be integrated into the project team or that should be hired by the company (two answers). Some companies noted that when the structural designs are undertaken by external offices, the structural components tend to be the oversized.

Choosing the structural systems

During the initial project definition, clients do not usually think about structural systems. Half the companies responded that it is rarely mentioned, while three considered that this aspect is never mentioned. The choice of structural types occurs frequently (seven responses) and occasionally (eight responses) simultaneously to the choice of the formal type. It is also frequent (nine responses) and occasional (three responses) that the choice is made after the formal type definition. Only in three cases was the choice of structural type done beforehand (frequently and occasionally). The simultaneous choice of structural and formal types occurs mainly in cases in which companies have an organized catalogue of solutions associating a structural type to each formal type. Some interviewees mentioned that when clients choose as a reference the catalogue solution, they already know which structural system will fit better.

The choice of the structural type which is usually held in the early stages of the project is done by considering the adequacy to the architectural solution as the most important criterion (nine responses "very important" and three "important"). The remaining criteria are less important, but economy is still the second most mentioned criterion, being considered as "very important" (four responses) or "important" (three). The other mentioned criteria are the construction schedule, the quality of the construction process and finally, the environment is considered a "less important" criterion (ten responses) or "not important" (four responses). Regarding codes and standards, the majority of responses devaluates its impact on the choice of the structural system, with most companies responding that their influence is less important or unimportant. However, the thermal requirements are those to which companies assign more importance over the other ones (structure, aesthetics, specific timber standards), with one "very important" response and four "important" responses. For the characteristics of the built envelope, seven companies said that different climatic zones have influence in their settings while eight said exactly the opposite. These latter companies said that the offered solutions always include the definitions to face in the most unfavourable situation.

The influence of structural types on the settings of formal types was considered mainly as "less important" (nine responses) or "unimportant" (two answers). The comparative analysis of structural systems is undertaken "often" or "occasionally" by seven companies, and "rarely" or "never" by the remaining eight. When questions were asked about the adequacy of structural systems to specific architectural characteristics, the responses were predictable, associating the post-and-beam to wide structural spans and larger windows, interior open spaces, stylistic flexibility, contemporary and "structural truth" character. The light timber frame panels were associated to stylistic flexibility, contemporary character and with minimized loads on the foundations. The log construction and the column-and-planks were associated to the "structural truth" character and the traditional character (though one company does believe that the contemporary character is also possible). The cross laminated timber panels are also mentioned, but less often (because only three companies work with them), associated to large spans, protruding volumes, stylistic flexibility and contemporary character.

Design process

Most companies (fourteen responses) can easily provide a construction cost estimate with a sketch drawing (1/200 scale), implying the existence of reference prices per square meter, although there are additional factors to consider such as the level of quality of finishes and the scale factor, reducing the price by square meter as the amount of work increases. With a design development project (1/100 scale), all companies already provide a final budget. Companies are flexible about the time the contract administration should take place, most of them (nine responses) considering that this step must only occur after the municipal approval is obtained. Throughout the interviews development, it was noted that the issue of construction documents (construction drawings) phase executed by the architect only occurs in some cases, as a large part of the details and specifications are made by the company. The detail drawings of architecture tend to be complementary (when they do exist) to manufacture and assembly drawings of the structure, envelope and interior partitioning. Seven companies think that the construction drawings must be coordinated by the company, while four answered that it should be a simultaneous process.

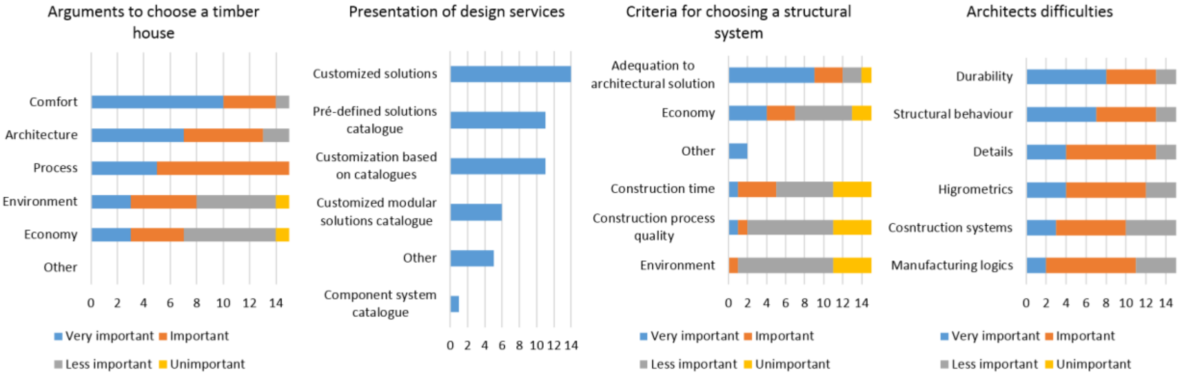

Figure 1 Some interview results based on 15 answers: (a) Arguments to choose a timber house (b) Presentation of design services (c) Criteria to choose a structural system (d) Architects difficulties.

ARCHITECTURAL DESIGN METHOD

An overview of the design process adopted by companies of timber houses and architects in Portugal can be described through the following three reference models (A, B, C):

A **-** Developed by the timber house sector companies. With solutions built from tested designs or catalogues or still modular systems (although contemplating customization). The companies have a preferred range of structural systems to offer. The architectural services in each project can be minimized due to the accumulated experience and the repetition of solutions. The advantages of this process are construction quality and process efficiency. Architecture in this case is understood as a product. The client chooses the product, but he must adapt himself to the company's standards and offer.

B **-** Developed by architects according to the model propagated by architecture schools in Portugal. With solutions based on the specific nature of each commission and ruled by conceptual principles or inspiring models of contemporary architecture, with the aim of obtaining unique and innovative features, with a large investment in aesthetics, more than durability. The architect integrates the well-known construction system with reinforced concrete. The architectural services are carried out with great endeavour in construction drawings. The advantages of this process are its formal quality and uniqueness. The resulting architecture is seen as an artistic product. The client chooses the architect, but he should adapt himself to the architect’s choices.

C **-** Developed by architects who provide services adapted to the reality of the average client of the single family houses in Portugal, with the aim of their satisfaction. With solutions based on preferred customer models and with reduced conceptual and aesthetic thought. The building system makes use of the current reinforced concrete. The architectural services are performed with reduced effort in construction drawings, using known details. The advantages of this process are the smaller costs of the design services, and the improved customer satisfaction, but the resulting architecture is often a rather banal product. The customer chooses the architect and this one must then satisfy his particular requirements.

We want to propose now an alternative system: D **-** To be developed by architects under a collaborative process with wooden houses sector companies. With solutions developed from a knowledge base made by a "catalogue" of architectural types which provides information on achievable solutions with timber structures, recognizing customer preferences but expanding the range of available solutions and the suitability to each scenario, with great emphasis in construction drawings, in durability concerns. The advantages of this method, compared to the process A, are the greater range of customer choices and the independent support that is provided. Regarding process B, communication and customer satisfaction are improved by a choice supported by a typological catalogue, seeking to obtain durable solutions. Finally, in relation to procedure C, there is the advantage of offering a personalized service with greater effort in architectural thought and greater conceptual attention to context and a more sustainable solution in wood.

Typological systematization

The typological systematization of the timber houses universe will be part of the information that allows us to acquire knowledge of market possibilities and that enable the communication between architect and client. The set of possible types results from the subdivision of architectural types into subtype systems. Thus, each architectural type includes a formal type and a construction type. The first is defined by features of architectural design, while the second is defined mainly by engineering features. The architectural type can in turn be subdivided into functional, spatial and symbolic types (Figure 3). The construction type can be subdivided into structural, envelope and partition types. Although the “types” can be described by rules, thus being different from "models" (or concrete solutions), it is useful to build a "catalogue" with models which represent the main types, because it will improve the communication between the client and the architect, avoiding misunderstandings. Dialogue can be established enabling the client to make choices from the various possibilities. On the other hand, architects can advise the client about the most adequate type of solutions without missing possibilities. The symbolic type is particularly important in the context of architectural types. It is defined in terms of characteristics, such as the roof shape, the degree of openness and the kind of finishing. The structural type (Morgado, Guedes, Ferreira, & Cruz, 2012) is of great importance in the context of building types, defined according to the characteristics of its vertical elements.

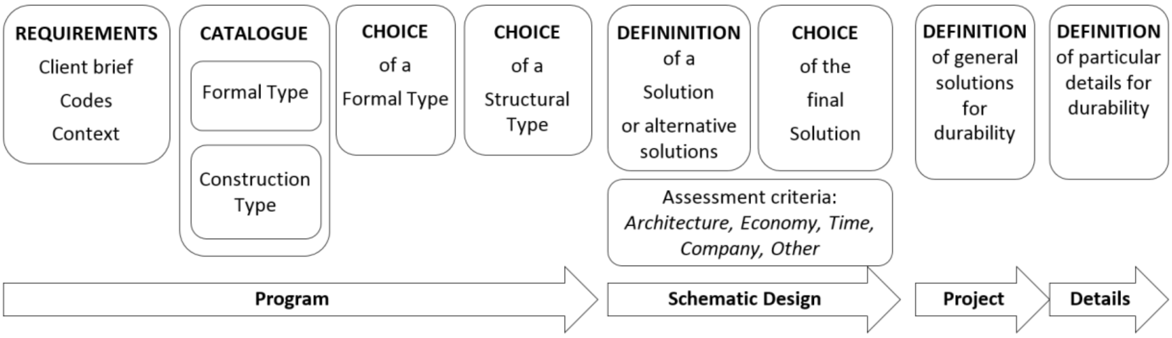

Figure 2 Proposed procedure based on architectural types.

Proposed design method

After the collection of data gathered from the context (codes, standards and customer requirements which include the functional requests, values and preferences, cost limits, time limits and environmental sensibility) the program is defined by the architect. The program will be based on the definition of successive types: functional type, spatial type and symbolic type which together define the formal type. After that the construction type will be defined: structural type, envelope type and partition type, but at any time the decisions can be questioned, thus implying a comeback to any previous stage. In the sketch design phase, solutions are developed and evaluated based on the selection criteria and respective weights defined in the previous phase. The structural solution (or structural solutions, in case there exist alternatives) will be evaluated based on the suitability to the architectural solution, the economy (including the costs provided by companies), the process (including deadlines and assessment of companies) and possibly on environmental impacts of the solution and also other criteria defined for each case. After the solution and the construction company have been chosen, the activity of the architect, besides the integration of all engineering services, will be focused on the architectural features that can ensure the durability of the building through the general settings and particular details.

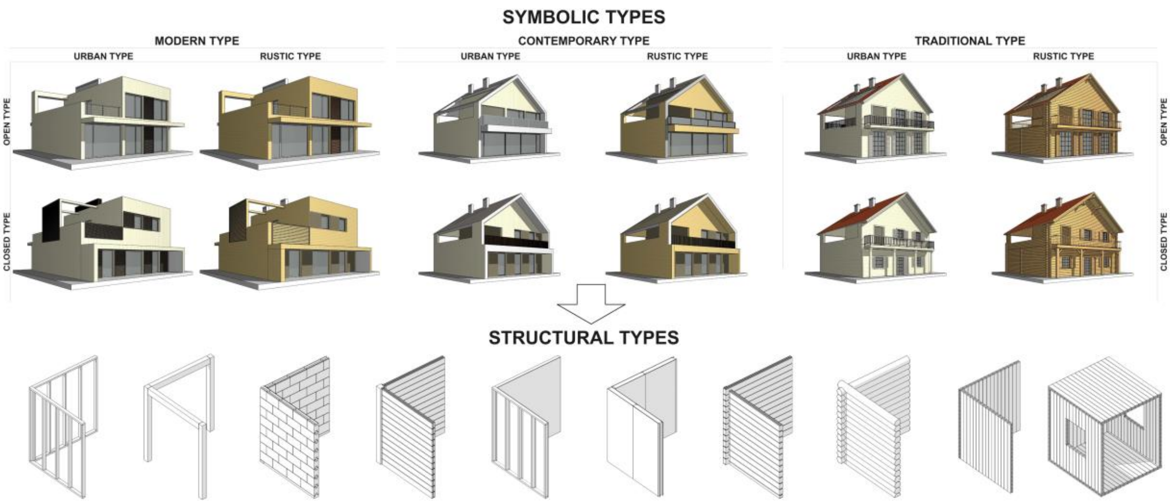

Figure 3 Example of a typological catalogue made by symbolic types and structural types

Following this proposal it is required that the architect welcomes a set of new practices and new skills: 1) It is required a knowledge of the cultural aspects of wood architecture to support the choice of formal types; 2) It is required a knowledge of structural systems and the understanding of its relation with architectural forms; 3) It is required an awareness of the criteria for selecting the structural types; 4) This calls for a better understanding of the specificities of wood and the constraints of durability. Architectural firms interested in building wooden houses could also define their own catalogues, following the suggestion of Colin Davies (Davies, 2005): "Pattern books could be used to promote the sale of certain commercial products, but more importantly, they could also be used to promote good architecture and sound, sustainable building practices (…) It seems completely feasible for architects to adopt, or readopt, the pattern book principle. It may even be an essential precondition for the achievement of that century old ambition to bring architecture to the masses".

CONCLUSION AND DEVEOLPMENT

Based on interviews conducted with the timber houses design, manufacture and construction companies, it was possible to recognize some important aspects of the national market and of the design process. Based on the information collected, the framework for a proposed method targeting the optimization of timber house design in Portugal was outlined. The information that had greatest impact on the proposal were: the existence and the importance of a typological catalogue, the relevant criteria for the choice of structural type (suitability for the architectural solution, cost limits and time limits), and the difficulties evidenced by architects in relation to wood construction. This last situation requires some actions to improve the knowledge about wood considering the solutions' durability. The details of this proposal are in development within a Doctoral Thesis, with several Portuguese companies supporting case studies aimed at testing the characteristics and constraints of each construction system.

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Window Components' Heat Control versus Orientation under the Extreme Hot Climate of the UAE

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ABSTRACT

The United Arab Emirates (UAE) has one of the world's largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy, used primarily for cooling due to its extreme hot climate. Recently, the government launched several housing programs intended to meet the need of future Emirati beneficiaries, of which the Emirati Family Housing Program aims at providing 13,000 detached residential units by 2017. Orientation of typical housing design is solely governed by urban planning layout. More critically, windows did not show any adapted heat control treatment in relation to orientation, despite the windows significant impact on heat gains under the local extreme hot climate. This study aims at optimizing the thermal performance of the window's components in relation to orientation in a typical house. The impact of orientation in the exsiting design indicated a 10% higher energy consumption for the west-oriented units compared to the east ones. Thereafter, the impact of window's components including glass (double reflective glass, double tinted Low-E and double squared Low-E), frame (vinyl) and a shading device (automated slated blinds) were tested. The best performing components were then combined into two scenarios: the first one included a vinyl frame and double tinted squared Low-E glass and the second had Low-E glass, vinyl frame and automated slatted blinds. The results indicated a reduction of the total annual energy consumption ranging between around 6% when facing east and 13% when facing west. More importantly, the optimal window components highlighted similar performance independently from orientation.

INTRODUCTION

The reduction of buildings' environmental impacts is an internationally agreed agenda. A number of studies have established that urbanization is one of the main drivers behind environmental impacts including global warming, depletion of natural resources and air pollution (Smith, 2005, Seto et al, 2011). The building sector in the United Arab Emirates (UAE) has experienced a tremendous expansion in the last forty years due to population growth and economic development. Presently, the UAE has one of the world's largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy. The residential sector in the UAE accounts for about 65% of newly constructed buildings according to the National Statistics Center (Statistics Center, 2013) and is responsible for 39% of the consumed energy, used mainly for cooling purposes (Saifur, 2012; RSB, 2013) (Figure 1). Amidst the overall country's growth, the residential sector developed in the form of extensive housing programs provided by the government to its citizens. The majority of these housing programs are in the form of detached houses, the most demanding type of houses in terms of cooling, especially under the local extreme hot climate (St Clair, 2009). A survey of housing typology in a representative community highlighted typical housing design where the units' orientation is solely governed by urban planning layout (Abuimara, 2013). More critically, windows did not show any adapted heat control treatment in relation to orientation, despite the windows significant impact on heat gains under the extreme hot climate. This paper presents the result of an experimental investigation that explored the potential contribution of advanced window's components to optimize the thermal performance independently from the impact of orientation while maintaining the architectural design unity.

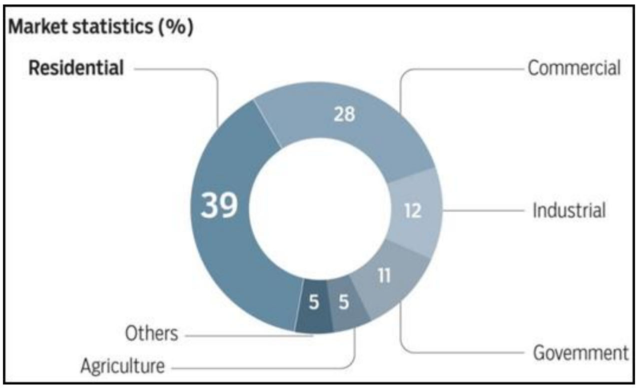

Figure 1: Energy Consumption by sector in the UAE (Source: Saifur, 2012)

HOUSING DESIGN, ENEGRY EFFICIENCY AND CLIMATIC CHALLENGE IN THE UAE

The UAE's desert climate, characterized by extremely high summer temperatures, imposes serious challenges to both designers and owners alike. Despite the extreme hot climate, controlled building thermal regulations were not introduced until 2003 in Dubai, addressing envelope insulation and glazing requirements in an attempt to curb the increasing energy issue in the building sector. These prescriptive insulation guidelines were then incorporated since 2011 in the Green Building Regulations (DEWA, 2014). More recently, the Urban Planning Council (UPC) in Abu Dhabi has established *Estidama*, the local green building rating system, This, aims at achieving sustainability and energy conservation in buildings through the provision of guidelines for newly constructed buildings. However, these guidelines are not fully implemented as they are still in the process of integration to the local building code (AlNaqbi et al, 2012).

Since the discovery of oil in the sixties, the UAE government amplified its intervention in the housing sector, acting as the main housing provider for its citizens at both federal and local levels. Governmental housing has evolved over time and comes currently in the form of communities that comprise a large number of detached houses (Abuimara, 2013). The *Emirati Housing Program* is the most recent program launched by Abu Dhabi Urban Planning Council (UPC), aiming to provide 13,000 detached houses until 2017 in the form of communities and neighborhoods in cities of the Abu Dhabi Emirate (UPC, 2011). These communities aim at the accommodation of social and cultural values along environmental adaptation through the design and construction of modern, high quality, sustainable units meeting *Estidama* requirements (Estidama, 2014). Al Falah Community; the research case study, located near the city of Abu Dhabi is part of the *Emirati Housing Program* and includes a substantially completed number of detached houses (ALDAR, 2009).

THE CASE STUDY; AL FALAH COMMUNITY IN ABU DHABI

Al Falah master planned community, part of Abu Dhabi 2030, has been designed to provide community facilities along with alternative social housing options for Emirati citizens. It consists of five residential villages with a total of 4,857 detached villas including a range of community amenities (Figure 2). Houses at Al Falah come in nine different designs varying in terms of size and architectural style. Villas come in three, four and five bedrooms typology ranging respectively from 300m^2, to 350 and slightly over 400m^2. All houses are located in large plots of over 1000 m^2 (30m x 35m), and surrounded by 2.5m high boundary walls (ALDAR, 2009). The villas were designed in 2008, prior to the development of Estidama; the local green rating system. They include some general sustainability measures including external wall and roof insulation, efficient water fixtures and high performing ventilation and air conditioning units (G.M.H. 2009).

Figure 2: Al Falah master plan community and aerial view of phase 1 (RIAS, 2013)

The three different architectural styles, labelled *Andalusian*, *Heritage* and *Modern* as illustrated in Figure 3, share otherwise the same layout (ALDAR, 2009). The master plan layout governs houses orientation with no indication of any window treatment adaptation per orientation.

Figure 3: The three different architectural styles (Andalusian, Heritage and Modern) of the same five bedroom layout houses in Al Falah community (ALDAR, 2009)

EXPERMENTAL INVESTIGATION

First, the dominant type of houses was identified through a typological classification survey of all houses. The five-bedroom villa emerged as the dominant type accounting for 50% of the total number of houses in Al Falah community, while 20% were 3 bedroom houses and the remaining 30% were four-bedroom houses (Abuimara, 2013). Next, a comparative evaluation of the Window to Wall Ratio (WWR) in all living spaces was reviewed and compared among the three architectural styles. Ranges of WWR of 24% to 30% and 50% to 60% were identified respectively for bedrooms and the living room indicating potential for window design optimization (Abuimara, 2013). The modern style house exhibited an overall slightly higher WWR than the other styles and was selected as the case study (Figure 4). Table 1 summarizes the characteristics of the base case including location and the building construction characteristics.

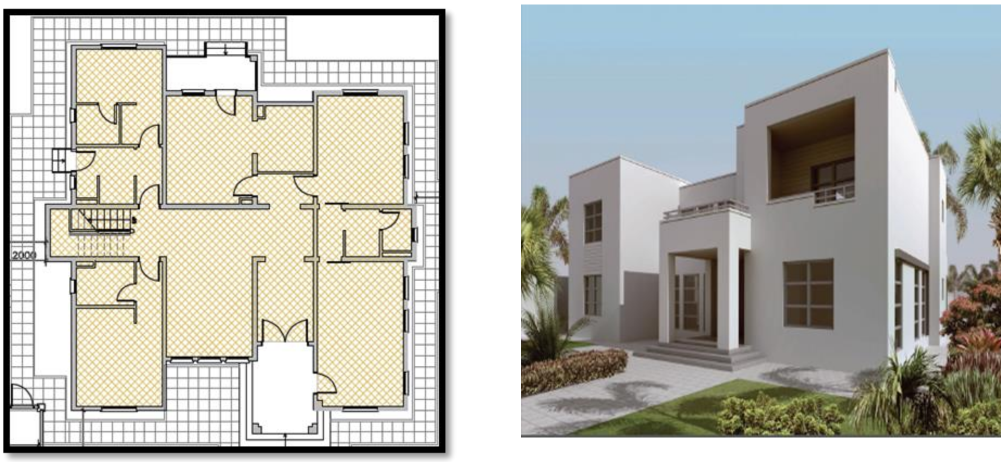

Figure 4: The dominant house type in Al Falah community; the five bedroom modern style house ground floor plan and main façade perspective

Table 1. The Base Case Characteristics

Category	Item	Description
Site	Location	Abu Dhabi 24.42^0 N, 54.65^0E
Area	Total Area (GF+FF)	402.36 m^2
	Footprint	212.56 m^2
Building Envelop Materials	Windows	Tinted double pane glass with air gap in aluminum frame (U-value= 0.81, SHGC = 0.45 and Tvis = 0.57)
	Walls	Insulated concrete panels. (20cm thick concrete panel with 6cm polystyrene insulation) R=11; Calculated using Opaque (Version 2) software based on the existing construction details
	Roof	Hollow core concrete slab with water proofing and heat insulation layers R=18; Calculated using Opaque (Version 2) software based on the existing construction detail.
	Wall / Ceiling reflectance = 70%	Colors range between white and cream (construction documents: ALDAR,2009)
Ratio of Glazing per Façade	Front Façade	26.55%
	Right Side Façade	13.4%
	Left Side Façade	9.03%
	Rear Façade	16.2%
Air Conditioning System	Package Unit	Seasonal Energy Efficiency Rate (SEER)=13
Indoor Temperature	Lowest indoor comfort degree = 21.1 C (70F)	According to California Residential Code
	Highest indoor comfort degree = 23.88C (75F)	

The impact of orientation on the thermal performance of the existing house design (base case) was first tested using the Home Energy Efficient Design software (HEED 4.0 build 34); software developed by the University of California Los Angles (UCLA). HEED is a dedicated energy evaluation tool for the thermal performance of houses and its outputs include among other data the annual electrical energy consumption, cooling loads and lighting loads.

The next step, in line with the original objective of this research explored thermally improved window components that do not impact the building architectural style. A reduction of window-to-wall ratio as well as addition of external shading devices as needed per each orientation were not considered. Hence, optimized glass alternatives and window frames were first individually assessed for each orientation in order to identify the contribution potential of single items. The glass and frames selection was based on their improved thermal properties and their availability in the market and included the tinted double pane Low-E glass, the tinted double pane Low-E squared glass and the tinted double pane reflective glass while the frame was limited to vinyl frame (Cardomy & Haglund, 2012). In terms of window shading, external operable slatted blinds were selected for implementation on all windows. These automated slatted blinds are light colored venetian blinds that close if the sun is on the window and interior temperature is above the set comfort level. The blinds are either fully open or fully closed. The selection of this type of automated blinds meets two requirements. First, they can be adjusted to suit all orientation in residential neighborhoods similar to the one under study, with thousands of houses allocated in different orientations that otherwise would have required specific shading designs for each orientation. Second, it maintains a distinctive uniformity as a specific orientation based design would have conflicted with the research objectives that aim at maintaining the architectural appearance of houses. Finally, a combination of optimum window components was carried out.

RESULTS AND DISCUSSION

Orientation Impact; Base Case

The impact of orientation on the annual thermal performance and the derived energy consumption was assessed. The annual electrical energy consumption, cooling loads and lighting loads for each cardinal orientation of the existing design are presented in Table 2.

Table 2. Base Case Annual Energy Consumption, Cooling and Lighting Load per Orientation

Power Usage (Kwh)	Orientation			
	North	South	East	West
Total Annual Electrical Energy	46,087	46,048	43,200	47,393
Cooling Load	29,455	29,434	27,163	30,400
Lighting Load	1,677	1,671	1,868	1,714

The first observation highlights a variable load for each orientation, emphasizing the impact of window design on the total energy used (Figure 5). The change of orientation with the main façade's higher ratio of glazing affected variably the annual energy consumption. The highest annual energy consumption rate was for the west orientation, while the east orientation displayed the least.

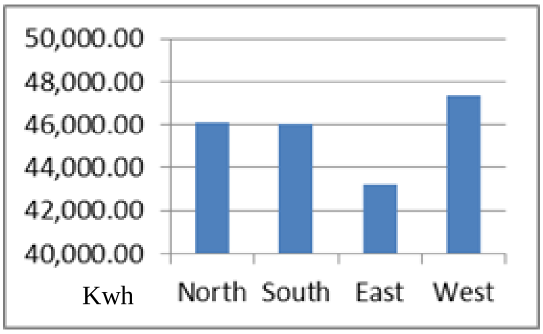

Figure 5: The Base Case Annual Energy Consumption per Orientation

The North and South orientation shared similar energy consumption rates.The recorded difference between the highest and the lowest annual energy consumption rates was 8.85%. This reduction in annual electrical energy consumption is linked to the reduction in cooling loads as it was reduced by 10.65% when the orientation changed from west to face east. This reduction can be explained as the east facing facade receives the least amount of solar radiation in the morning while the temperature is still low while the west facing receives the afternoon and evening direct solar radiation along with transmitted heat at day heat peak times. Finally, despite the use of window system with tinted double pane glass in the original design, the impact of orientation heat gains as verified remains, justifying the need to explore further the optimum potential of window components' heat control.

Thermal Performance Optimization

A vinyl frame with thermal break and three alternate types of glass were considered as indicated along their chgarcateristics in Table 3. The impact of these single component changes on the annual energy consumption per orientation is presented in Table 4 and Figure 6 for the glass alternatives contribution.

Table 3: Thermally Improved Glass Alternatives

Variable	U-Value	SHGC	Tvis
Tinted double pane glass, Aluminium frame with no thermal break (Existing Design) – Base Case	0.81	0.45	0.57
Tinted double pane glass, Vinyl frame (thermal break)	0.51	0.38	0.57
Tinted double pane Low-E glass, Aluminium frame	0.69	0.39	0.53
Tinted double pane Low-E squared glass, Aluminium frame	0.67	0.25	0.38
Tinted double pane reflective glass, Aluminium frame	0.81	0.16	0.09

Table 4. Total Annual Energy Consumption for Optimized Glass

Variable	Total Kwh			
	North	South	East	West
Base Case	46,087	46,048	43,200	47,393
Tinted double pane glass, Vinyl frame	43,624	43,571	41,464	44,664
Reduction	5.35%	5.38%	4%	5.76%
Tinted, double, Low E-Glass	44,626	44,580	42,225	45,709
Reduction	3.17%	3.19%	2.26%	3.55%
Tinted, double, Squared Low E-Glass	43,072	43,045	41,846	43,663
Reduction	6.54%	6.52%	3.13%	7.87%
Tinted, double, Reflective Glass	44,665	44,616	43,573	44,869
Reduction	3.10%	3.11%	-0.86%	5.33%

The results indicate that the highest savings in total annual energy consumption were obtained for all orientations with the double tinted squared Low E glass. The savings were from almost 8% in the case of west-facing house, 6.5% for the north and South and 3% in the case of east-facing one. The vinyl frame outperformed the aluminum one and contributed with a 4% reduction for the east façade and slightly about 5% for all the other orientations.

It should be noted that the total annual electrical consumption does not highlight the differential impact of each type of glass on lighting and cooling loads. On these grounds, the tinted doubled Low E glass generated 6% to 10% savings in cooling loads in comparison to the base case, indicating better heat control. The double reflective glass on the other hand, produced fewer saving because of the excessive lighting loads which ranged between 110% and 130%, due to the low visible transmittance of the reflective glass which led to an increased dependency on artificial lighting. In summary, if the double reflective glass indicates a better heat control, this is countered by its low light admission that will adversely affect lighting load, leaving a negative annual energy usage balance.

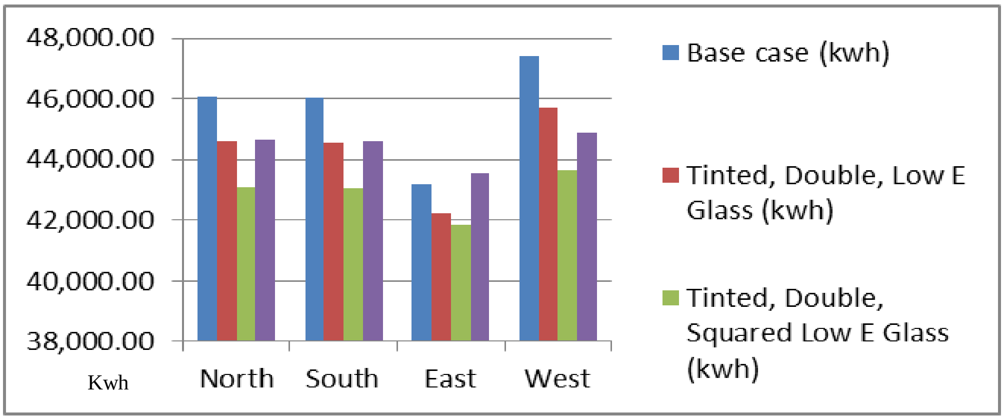

Figure 6: The Annual Energy Consumption per Orientation for Alternative Glass Options

Window Systems Thermal Performance Optimization

The next step consisted of optimised combinations of glass, frame and one type of shading devices. Two scenarios were considered; the first thermally optimized window system consisted of a vinyl frame with the double squared low-E glass and the second scenario had a vinyl frame, double low-E glass and shading in the form of light colored automated slatted blinds. The results indicate savings from 6% to almost 12% for the first scenario (Table 5 and Figure 7). Of more relevance, it should be stressed that the four orientations yielded similar annual energy consumption with marginal variation (1 to 3%) compared to the base case.

Table 5. Total Annual Energy Consumption for Optimized Window Systems (Scenarios 1&2)

	Total Kwh			
	North	South	East	West
Base Case	46,087	46,048	43,200	47,393
Scenario 1: Tinted, Double, Squared, Low E+ Vinyl Frame	41,407	41,429	40,551	41,839
Reduction	10.15%	10.03%	6.13%	11.72%
Scenario 2: Vinyl Frame +Low E Glass+ Slatted Blinds	41,136	41,046	40,439	41,107
Reduction	10.74%	10.86%	6.40%	13.26%

The second scenario with vinyl frame, Low E-Glass and automated slatted blinds carried a potential annual energy savings from 6.5% for the east and up to 12.7% for the critical west orientation (Table 5 and Figure 7).

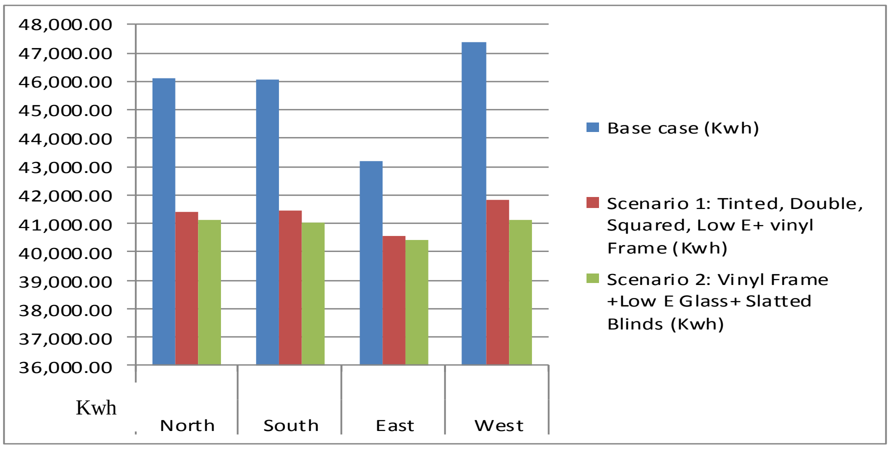

Figure 7: Total Annual Energy Consumption for Optimized Window Systems (Scenarios 1&2)

These savings are due to the reduction of direct solar gain which is being blocked by the automated shading device and the reduced transmitted heat the usage of low E glass. The variation of the thermal performance between orientations ranged from 1 to 3% compared to 8.85% between east-facing and west-facing house in the base case.

CONCLUSION

This research has investigated the thermal optimization of windows components in relation to orientation in a representative governmental housing project in the UAE. The thermal performance of the dominant house type was first tested in relation to the cardinal orientation. The west facing house carried almost 9% more annual energy consumption than the east orientation. Then, single window components were tested for the energy savings potential. A vinyl frame with thermal break and three efficient glass alternatives were identified, and tested including: double reflective glass, double Low-E glass and double squared Low-E. The latter provided optimum performance with savings ranging from 3% to 8% of the total annual energy consumption, repectively for the east and west orientations while the vinyl frame with the original glass type yielded between 4% and 5% energy savings. Subsequently, the most effieicnt components were combined and tested. The double squared Low-E tinted glass and vinyl frame yielded savings ranging from 6 % to11.7% respectively for the east and west orientation. More importantly, the optimal window components highlighted similar performance independently from orientation, thus enabling flexibility in housing planning projects with increased thermal efficiency and energy savings.

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Investigation of thermal resistance and bridging in examples of contemporary and vernacular solid wall architecture

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ABSTRACT

Contemporary architecture has tended to increase envelope insulation levels in an unceasing effort to reduce U-values. Traditional masonry architecture in contrast was devoid of insulation, except for the inherent insulative nature of vernacular materials. Also the consistency of the outer membrane of the building skin diminished any impact due to bridging. In contemporary highly insulated walls bridges are numerous due to the necessity to bind inner and outer structural skins through insulation layers. This paper examines thermal bridging in an example of contemporary façade design and compares it with an example of traditional vernacular architecture currently being researched which is characterized by a lack of bridging elements. Focus is given to heavy weight materials of high thermal mass, which appropriately for passive architecture help moderate fluctuations in internal temperature. In an extensive experimental study samples of highly insulated precast concrete sandwich panels and lime rendered masonry walls are tested in a guarded hot-box. The building construction methods are compared for static and dynamic thermal transmittance, via heat flux and surface temperature differential measurements. Focus is given to the differential heat loss due to the thermal bridging in the sandwich panels and its associated impact on overall heat loss relative to traditional masonry construction.

INTRODUCTION

Building envelopes are becoming increasingly capable at retaining heat. European and national regulations are emphasizing ever-lower U-values, increasing pressure on building designers to augment the insulation content of walls so as to meet these targets.

Standard domestic construction is generally either of solid masonry wall, timber or steel frame construction. Focusing on solid wall construction, Stazi et al. (Stazi, Vegliò, Di Perna, & Munafò, 2013) define the 3 different wall construction categories common to temperate climates as (i) *capacity*, (ii) *stratification* and (iii) *resistance*. In Western Europe since mid 1900s cavity wall (*stratification*) construction has prevailed (Hens, Janssens, Depraetere, Carmeliet, & Lecompte, 2007). Prior to the postwar emphasis on cavity wall *stratified* construction, solid or *capacity* walls were common. Monolithic or rubble stone walls were common in vernacular construction, and still constitute the envelope of many farmhouse and cottage architecture in the European and Irish context. Today many of

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this building stock is in need of thermal upgrade. Contemporary insulation materials trap moisture and prevent these traditional structures from 'breathing'. Novel alternatives based on natural, sustainable materials are required.

Today cavity walls are often in the 3rd category described by Stazi, *resistance*, given that many have been either retrofit with pumped interstitial insulation or augmented with a layer of internal or external insulation. Another type of *resistance* wall is the precast wall, or sandwich panel type. This construction type, which is becoming increasingly popular in Europe and is already well established in the tilt up construction market of the US, is endowed with the benefits of prefabrication which ensure time, cost and quality efficiencies of factory floor construction. In multi-story construction precast sandwich panels (PCSP) must be designed to ensure composite action between the interior and exterior concrete wythes. Lower U-values imply thicker insulation layer, which in turn implies larger tie elements, often metallic and hence highly conductive of heat. So even though specified U-values might be achievable using high levels of insulation, the thermal bridging impact of the ties becomes relatively more significant as the insulation gets thicker, a phenomenon now well established (Mao, 1997).

There are a number of reasons why PCSPs are specified (robust nature, finished surface etc.) but primary amongst these is their superior thermal mass properties over lightweight construction alternatives. They might be viewed as closer in thermal mass terms to traditional solid wall structures than to contemporary frame structures. They have a *capacity* likely to impact on the internal thermal environment however, the heat transmission to the outside is minimized due to the interstitial insulation layer. However, thermal bridges are numerous in PCSPs (Lee & Pessiki, 2006). Thermal bridging in contemporary facades has long been recognized as a significant failing in the *resistance* model of façade design with some authors claiming up to 30% of building heating requirements are given to façade thermal bridges (Theodosiou & Papadopoulos, 2008).

This paper investigates *R* and *U*-values in two wall construction methods. The construction types are disparate but enable exploration of the impact of thermal resistance and bridging in contemporary (insulation heavy) solid wall construction in contrast to a sustainable, vernacular-appropriate, alternative (with inherent insulation properties). These are compared and contrasted with past research in the literature that documents thermal bridging in other common construction methods, including frame construction. The theoretical *U*-values are compared with the real *U*-value calculated experimentally via hot-box testing procedure. The traditional envelope consists of an insulating lime-hemp render applied to the external of a solid brick masonry wall. Lime-hemp is under general research investigation by these researchers as an appropriate 'breathable' insulation method for historic building renovation. An example contemporary envelope is investigated via PCSP samples. These sandwich panels include significant insulation layers. Although the U-value when analysed both with and without the impact of thermal bridging is relatively low the relative impact of thermal bridging is significant and needs to be accounted for.

METHODOLOGY

Experimental and simulation studies were undertaken. The experimental program was based on five wall samples; (i) a solid clay-brick masonry wall bound with hemp-lime mortar, (ii) a lime-hemp (2:1 by mass ratio) render applied to (i), (iii) a lime-hemp (1:1.25 by mass ratio) render applied to (i), (iv) PCSP with 240mm insulation and 240mm deep, 3mm thick bridging plate, (v) PCSP with 160mm insulation and 80mm deep, 2mm thick bridging plate. The impact of the bridging plate was then investigated using a simplified Finite Element Model (FEM) that was developed.

Experimentation

A one-sided hot box is used to measure the total amount of heat transferred from one side of the specimen to the other for a given temperature difference, irrespective of the individual modes of heat transfer. The internal environment is tightly controlled (at 35°C) however the external environment vary with ambient indoor conditions. EN ISO 8990 and ASTM C1363-05 specify similar hot-box testing procedures and methods of heat exchange calculation. Neither consider the sample configuration but instead calculate the total heat transfer that passes through the sample under test based on recorded heat flux and temperature values (Asdrubali & Baldinelli, 2011). According to BS ISO 9869-1 data is taken for a minimum of 3 days for each heat flux recording and care is taken to choose days of minimal temperature variation. Samples taken every 10 minutes are averaged according to the average method described **by equation (1)**.

The steady state thermal resistance of the wall (R_t) can be calculated by,

$$R_t = \frac{\sum_{j=1}^{n}(T_{Sij}-T_{Soj})}{\sum_{j=1}^{n}(q_j)} = \frac{T_{Si}-T_{So}}{\emptyset/A} = \frac{\Delta T}{\emptyset/A}\ (m^2K/W) \quad (1)$$

where, T_{si} and T_{so} are inside and outside surface temperatures, ϕ is the heat flux over area A.

The R_t value is measured via experimental testing. To calculate the U values, standardized surface resistance on the inner and outer wall surfaces are added to R_t. These are given in EN ISO 6946 as R_{Si} = 0.13 m2 K/W and R_{So} = 0.04 m2 K/W in the case of horizontal heat flux (Martin, Campos-Celador, Escudero, Gómez, & Sala, 2012).

$$U = \frac{1}{R_T} = \frac{1}{R_{Si}+R_t+R_{So}} \quad (2)$$

The whole building heat loss might then be characterized (CIBSE Guide A, 2006) using the equation,

$$H_t = \sum AU + \sum L\psi \quad (3)$$

where, H_t is the whole building heat loss, A is the area of all surfaces, Ψ is the thermal bridge and L is its length of thermal bridges.

A number of methods of calculating thermal bridging in PCSPs with varying levels of accuracy have been proposed in the literature, as previously reviewed (O'Hegarty & Kinnane, 2012). For a 2D analysis Griffith et al (Griffith, Finlayson, Yazdanian, & Arasteh, 1997) present a THERM based parallel path method of U-value approximation that is adopted here. Given their depth to thickness ratio the bridging plates in this study might be approximated to propagate heat in the 2D plane. The parallel path U-value (U_p) is given by,

$$U_p = F_B U_B + F_N U_N \quad (4)$$

where F_B is the fraction of bridged section and F_N is the fraction of non-bridged section.

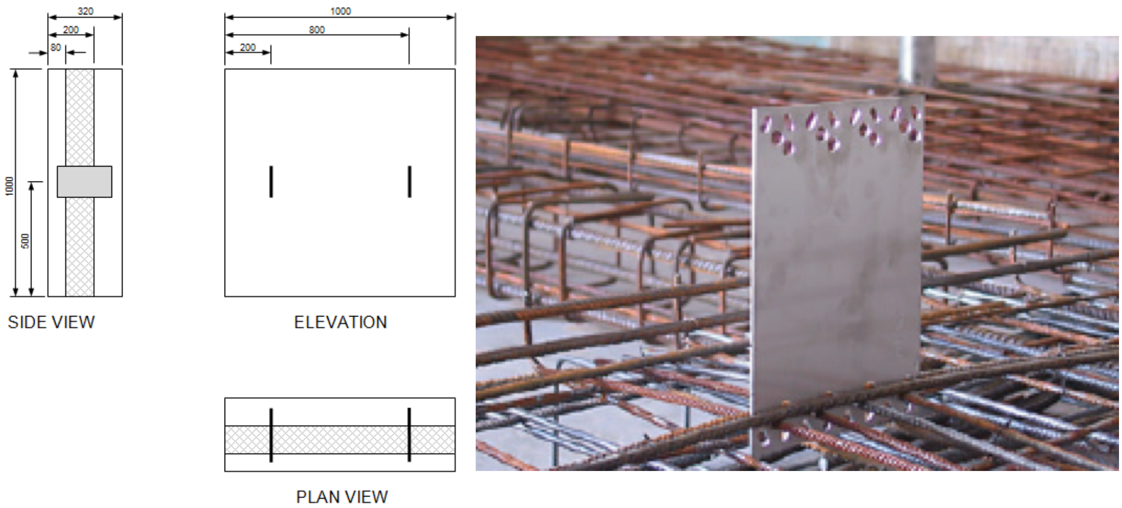
To further evaluate the effect of thermal bridging in the precast panels in this study a FEM was developed. The model was a simplified representation including concrete, insulation and plate geometry and properties, but without reinforcement detail.

Masonry Walls. Figure 1 shows the 1m x 1m brick masonry wall (**Figure 1 a)**) and lime-hemp render subsequently applied to one half of the wall (**Figure 1 b)**). A second and different mix is applied to the other half of the wall and both are monitored for heat loss (**Figure 1 c)**). No thermal bridging is evident in the 1m^2 section of masonry wall, and the lime-hemp render is homogenous over the complete surface of the wall. Two lime-hemp renders were investigated with different proportions. Mix 1 was based on the standard mix commonly used in industry – proportions 2:1, lime:hemp. Mix 2 reduced the lime content and increased the hemp content with the aim of achieving greater thermal insulation – proportions 1:1.25, lime:hemp. The brick is a filled-clay, machine-pressed brick, presoaked and bound with a Natural Hydraulic Lime 3.5 mortar. Approximate density and thermal conductivies are 1200 kg/m^3 and 0.36 W/mK respectively (CIBSE Guide A, 2006).

a) b) c) d)

Figure 1 a) Masonry brick wall, b) one half of wall rendered with lime-hemp render, c) heat flux probes and surface temperature sensors installed for hot-box testing, and d) infra-red image during testing.

Precast walls. Two precast concrete sandwich panels (1m x 1m) were tested in the guarded hot-box. An example panel configuration **is shown in Figure 2**. The exact plate and panel configuration **is given in** Table 2. The plates that are responsible for ensure composite action are also **shown in Figure 2**. These are threaded with reinforcement bar prior to casting. The exterior wythe of both panels is 100mm, the internal wythe which is structurally salient is 120mm. The wythe of insulation layer varies from 240mm in panel 1 to 160mm in panel 2. The insulation is Expanded Polystyrene (EPS) with thermal conductivity of 0.035 W/mK. Approximate density and thermal conductivy for concrete are 2200 kg/m^3 and 1.7 W/mK respectively (CIBSE Guide A, 2006).



a) b)

Figure 2 a) precast sandwich panel configuration, and b) example of plate tie used and method of attachment to rebar prior to casting of concrete.

RESULTS

Key results for the hot-box analysis of the brick masonry and PCSPs are documented in subsequent tables.

Masonry walls. The results of the hot-box and thermal resistance tests are presented **in Table 1**. The thermal benefit of adding the lime-hemp insulative render to different wall types is evident. The thermal resistance increases by approximately 50% with the addition of 21mm lime-hemp render layer.

Table 1. Experimental heat flux, *R* and *U*-values of the brick masonry with lime-hemp render

Wall construction	Heat Flux W/m^2	R-value m^2K/W	U-value W/m^2K
Brick and lime mortar	48.35	0.175	2.89
Brick and lime mortar with lime-hemp render (Mix 1)	36.5	0.259	2.33
Brick and lime mortar with hemp lime render (Mix 2)	37.74	0.274	2.25

The lime-hemp render can be seen to add an additional 0.084 m^2K/W and 0.1 m^2K/W to the bare brick masonry wall R-value.

Precast walls. Precast concrete sandwich panels were investigated for overall thermal resistance and for the effect of bridging. Aggregated results of hot-box tests for the two panels are described **in Table 1**.

Table 2. Key dimensional parameters and experimentally calculated heat flux, *R* and *U*-values of the precast concrete sandwich panels

Panel and Plate dimensions		Heat Flux W/m^2	R-value m^2K/W	U-value W/m^2K
Panel 1. Insulation width -240mm Plate width - 350mm	Plate thickness - 3mm Plate depth - 240mm	4.24	4.54	0.22
Panel 2. Insulation width -160mm Plate width - 260mm	Plate thickness - 2mm Plate depth - 80mm	4.69	3.13	0.33

Heat flux values are low in both PCSPs as might be expected given the considerable quantity of insulation within the panels. Panel 1 with 240mm insulation has a 45% greater thermal resistance than Panel 2 with 80mm extra insulation.

Table 3. Experimental evidence of thermal bridging due to plate connectors in precast sandwich panels

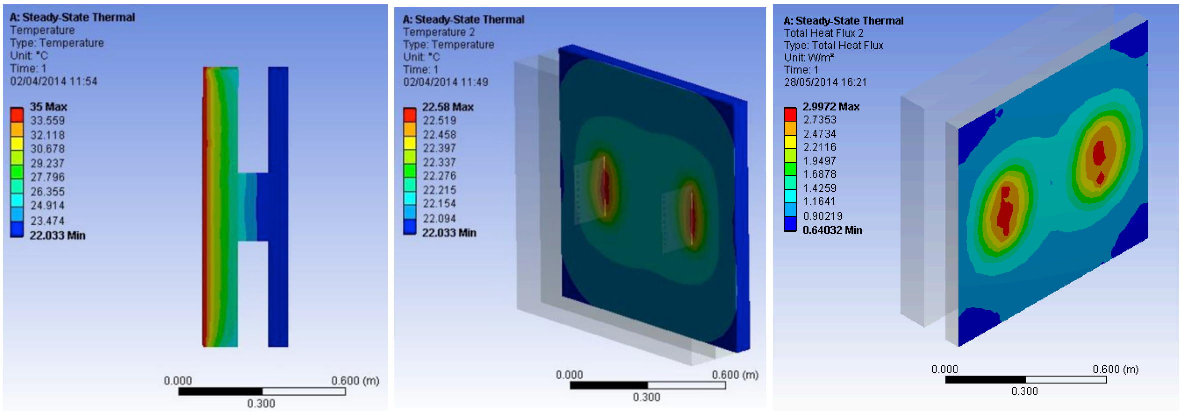
Panel and Plate bridge dimensions	U non-bridged location	U bridged location	U % locational difference
Panel 1.	0.22	0.45	104%
	0.33	0.49	48%

Panel 2.

The heat loss through the concrete surface is considerably greater at the location of the plates than over the centre. The plates are 55mm below the surface yet the heat flux increases from 4.24 to 10.46 W/m^2 in Panel 1 and 4.69 to 9.9 in Panel 2. The effect of bridging is relatively considerably more evident in Panel 1 than in Panel 2. This is due to the greater depth (240mm vs 80mm) and thickness (3mm vs 2mm) parameters of the plate.

A 240mm deep plate is 24% of the cross section of the panel, and an 80mm plate, 8%. Using the parallel method **equation (4)** the U-value for Panel 1 and Panel 2 can be corrected to 0.277 W/m^{2}K and 0.34 W/m^{2}K respectively, to account for the thermal bridging along the line of the panel.

Finite Element Model. Results of the FEM model of the precast concrete sandwich panel are shown in Figure 3. The steady state heat profile is shown in Figure 3(a) when the interior wythe of concrete is heated in a hot-box to 35^{o}C. The temperature at the internal face of the exterior wythe, on the other side of the insulation later, of the precast sandwich panel is as low as 23.7^{o}C. The model shows minimal temperature impact of thermal bridging on the panel with the outer face of the exterior wythe only fractionally higher (0.3^{o}C) than standard room temperature 22^{o}C.



a) b) c)

Figure 3 a) FEM thermal analysis (simulation of concrete wythe heated to 35^{o}C in a hot-box), (hot-box and insulation hidden in model). b) Isolated solution showing temperatures at interior face of external concrete wythe and, c) Heat flux through front surface of panel

CONCLUSIONS

This paper presents an experimental study of two solid walls, an example sustainable vernacular construction and an alternative highly insulated contemporary, solid wall constructions. Both constructions have their individual strenghts. In the vernacular construction, sustainable materials with less well recognized insulative ability are investigated. Brick and stone solid walls are characterized by low U-values, however introduction of the lime-hemp render layer enhances the thermal resistance of solid architecture construction by up to 16% in some cases, and 50% on the single leaf brick wall. Even with the addition of the lime-hemp render the thick vernacular masonry walls listed **in** Error! Reference ource not found. retain high *U*-values. However, given their lack of spot bridging, thermal capacity capability and recognized benefitial impact on the internal environmental conditions in appropriate climates (Martín, Mazarrón, & Cañas, 2010), traditional solid solid wall constructions retain advantages over contemporary façade systems. These walls are generally also devoid of thermal bridging.

In the example of solid but panelised contemporary wall construction, although the U-value of the wall is low due to a significant insulation layer, thermal bridging exists and effects the overall thermal performance. However, given the relatively small area over which it acts its impact is not seen as a considerable deficiency. Next stages in this research study involve analysis of the thermal mass effects of both wall types. The walls will behave differently in dynamic environments. The position of the insulation layer within the build up of the contemporary wall reduces the fluctuations in temperature that the sandwich panel wall will experience relative to a solid alternative.

The study is not without its limitations, and these are subsequently outlined. The hot-box used is somewhat more primative than that used in past studies – given that its made of four walls created by layering insulation panels - however it can offer approximate thermal resistance values. A limitation of the study is the impact of dynamic environmental conditions on the ambient air on the cold side of the hot-box. Although the surface temperatures vary in a very narrow range (~2-3°) relative to the ambient air temperature fluctuations (~5-6°). Another matter that should be noted is that the steady state modeling study returns lower heat flux values, of up to 33%, than the experimental study. The model does not capture the reinforcement bar and hence the conductive route of bars to plate is not modeled. The bars lie perpendicular to the plates, but contact them at a number of locations.

Further research aims to develop accurate models of thermal bridge in solid wall construction and to investigate alternative sustainable insulation materials. The transient effects of thermal bridging and its impact on thermal storage and diffusivity will be investigated through experimental and numerical simulation. This paper outlines some of the basis for this research by investigating examples of traditional, *capacity,* wall types, and contemporary, *resistance* wall types through an experimental steady state evaluation.

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NOMENCLATURE

R_t = thermal resistance

R_{Si}, R_{So} = thermal resistance of inside surface and outside surface

U = thermal transmittance

Ψ = thermal bridging

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Session PF : Vernacular architecture

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Progress - Knowledge Consortium of Gujarat

Diurnal Radiative Cooling of Spaces in Mediterranean Climate

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ABSTRACT

The absence of solar radiation at night gives good opportunities for passive cooling of buildings in hot climates with frequently clear sky. However the possibility of also taking advantage of a clear sky cooling potential during the day is seldom considered.

Thermal radiation to sky can be used to cool. A body surface emits thermal radiation (far IR) and if direct solar radiation (visible and near IR) and thermal radiation coming from other surfaces do not reach it, there would be a net heat flux out.

A previous prototype was done with a simple element. That experiment confirmed that was possible to reduce around two degrees the interior temperature of the test unit exposed to sun light in July.

In this work a new design based on the first one is developed to adapt it to architectonical needs in order to reduce interior spaces temperature in hot climates.

The aim of this design is focused to so an architectonical adaptation is needed. Modular and replicable units could be a solution that permits to fulfill large flat surfaces as roofs or other architectonic elements. In this occasion, measurements were taken from a modular model with a geometrical design that avoided de direct solar incidence. These measurements were taken by a pyrgeometer during two weeks of August and results were similar to the previous experiment.

INTRODUCTION

A body surface emits thermal radiation (far InfraRed, IR), and if it can be made that direct solar radiation (visible and near IR), and thermal radiation from other bodies (far IR) do not reach the body surface, there would be a net heat flux out of the body, cooling it (Head 1962). The cooling can be obtained by selective surfaces, that reflect visible and near infrared solar radiation (near IR), avoiding direct solar gains, while they are emitters for far infrared radiation, if they are appropriately exposed, and allowing radiation going to sky. Cooling can also be achieved with the help of reflective surfaces and geometry (Trombe 1967 and Hull 1986). A polished surface with high reflectance to infrared radiation is able to reflect the image of the sky and maintain the radiation characteristics (Granqvist 1982). An emitting surface "seeing" the reflected image of sky, will loss energy to the reflected part of cold sky (Craig et al. 2008).

The previous prototype tested in Barcelone was done with a single element (Serra et al. 2010). In that occasion, the analysis let us know that it is possible to reduce the inside temperature of a chamber, in about two degrees, during the sunny hours if an emitting surface can see nothing but the cold sky zone and its emitted radiation is thrown far away without reflection that take it back. That prototype checked the effect with a single element covering the entire top side of the box. The vertical development was very high and this dificults the practical applications in architecture.

In this work we consider the possibilities of irradiative cooling in Mediterranean climate for cooling interior spaces of buildings. We want to test a variant of the first model that incorporates the principle refrigerator to a replicable element that fill a flat roof being easy to construct and modular. The second main goal is about the system should use cheap, easily available materials in the existing industry such us aluminum foil and cardboard.

To face this challenge we have deepened the geometric study of the protection element of the emitting sheet, so that the surface occupied by the protection system was reasonable and the effective emitting area was the largest as possible. Geometry must help us to make that the emmiting surface only would see the cold zone of the sky even by reflection.

The emitting surfaces were white painted metal sheet as in the first model. In order to reduce thermal exchange with exterior air (Johnson 1975, and Golaka et al. 2007), we installed a thin 50 µm transparent polyethylene film 3 mm before the emitting surface. In this way the polyethylene film does not receive direct solar radiation and its life is expected to be longer because no significant UltraViolet (UV) radiation reaches the film. The test model was made with common materials and located in a village near the Mediterranean coast, and measurements were taken, by a pyrgeometer, during two weeks of August.

GEOMETRICAL APPROACH

Those two features, an easy construction and avoid IR radiation, can be both obtained if a suitable geometry for a lateral screen system is designed. We did a very detailed study of the geometry of the unit module. Such geometry should comply with the protection requirements of solar incidence both direct and reflected. The geometric study started from the solar path during the worst day -summer solstice- on a stereografic diagram, to narrow the sky zone without the sun passing throw, see Figure 1. Zones 1 and 2 on the diagram represent the coolest zone of celest voult, away both from the sun path and from the horizon, to avoid radiation emitted from extern objects that could reduce the net heat flux out from our emitting surface.

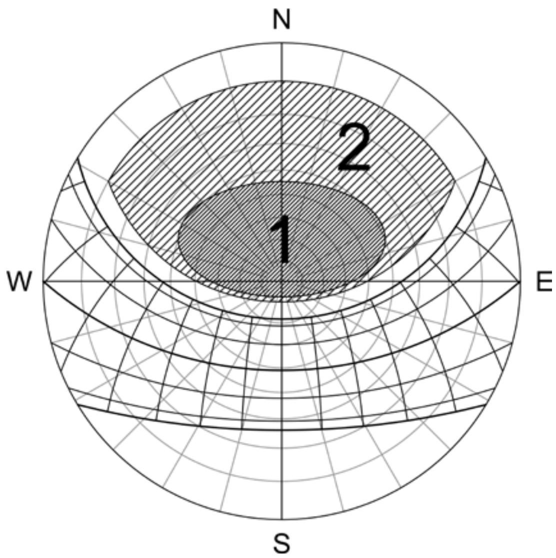

Figure 1 A stereographic diagram for Barcelona, near 41º north latitude. Zones 1 and 2 are preferred for thermal radiation exchanged. Zone 1 has lower equivalent radiant temperatures.

The vertex of a 134º opening cone, looking to the correct direction to the north for this latitude about 41º north, will never see the sun it sees the cold sky zone (see figure 2). We must place the emitting surface behind the initial vertex to obtain a large enough area for the irradiative surface, although this brings up a narrower conical element. So we extended the generatrices of the cone beyond the vertex looking for an ortogonal angle with the opposite sheed to avoid reflected rays coming back. Then we transformed the cone to a pyramidal piece because planar forms are more usefull to replicate and add elements. This choice should provide an eligible prototype for construction useful to add units in order to fulfill a roof.

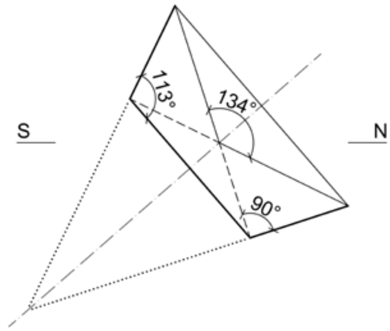

Figure 2 The diagram shows the overture of the first conical unit element with an overture of 134º toward the cold zone of the sky, and the geometrical definition of the replicable pyramidal unit.

Finally the side flaps were extended to protect the interior of possible radiation reflected in them and even folds were we calculated graphically the correct angle to improve the efficiency of the global suitable surface. Lateral slopes in contact to the emitting surface respond to the pyramid design explained above, bottom slope was further worked in order to maximize the efficiency. Its tilt was modified in the far part because the high of incident solar rays in that point was minor and if we fold it back we can reduce the occupied roof area by each basical unit (see figure 3).

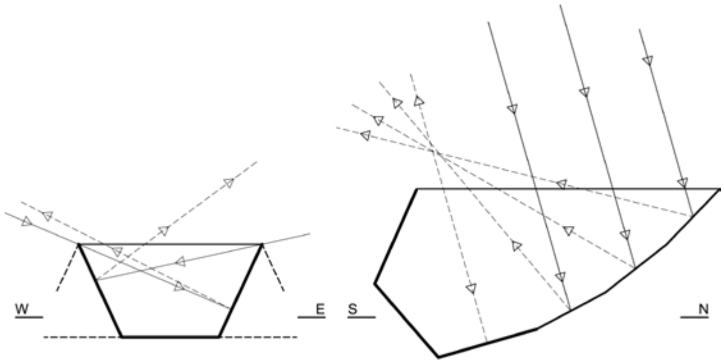

Figure 3 Shows the two sections of the basical unit and the reflected sun rays of sun on the side screens. Folding the northen screen reduces the ratio between emiting surface and global roof surface.

Different units can be easily aggregated. Some faces are extended in order to cover the horizontal roof with high performance. Lateral extreme screens are also extended to avoid sunlight entering during the first and last hours of the summer days. As a result of this process, we obtain a geometric model with an effective surface area of 1/6 of total roof area.

PROTOTIPE AND MESUREMENTS

The roof model was installed on a 50cmx50cmx30cm box, with 7 cm of expanded polystyrene thermal insulation, see figure 4.

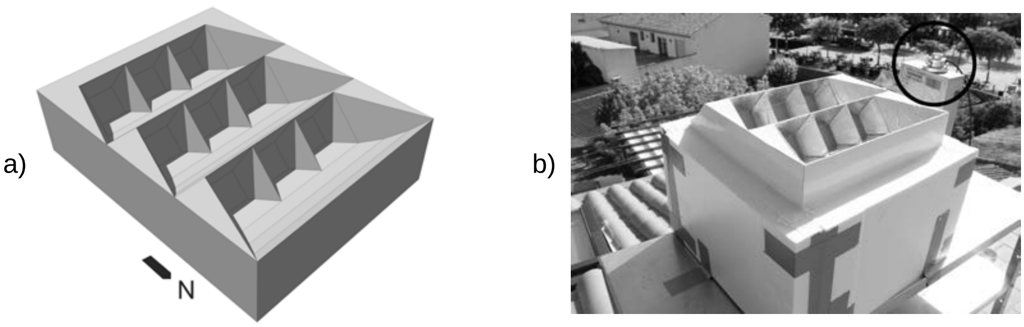

Figure 4. a) Digital 3D model. b) Photograph of the built prototype. The circle shows the pyrgeometer.

The emitting surfaces were white painted metal sheet. In order to reduce thermal exchange with exterior air (Tazawa 1996, and Tazawa 1997), we installed a thin 50 µm transparent polyethylene film 3 mm before the emitting surface. In this way the polyethylene film does not receive direct solar radiation and its life is expected to be longer because no significant UV radiation reaches the film.

The model has been checked during a period of sunny days of August, in a roof of a house in Sant Llorenç del Penedés (near Barcelona).

Measures of thermal emission have been done with a Pyrgeometer 1239 from Hukseflux thermal sensors with a Cambell Scientific datalogger 21538, and compared with solar radiation from a Pyranometer at the automatic meteorological station (XEMA 2013) placed in El Vendrell (5 km from the scale model). Both devices measure total (direct and diffused) radiation in different wavelengths.

The obtained results for the modular case show that during some sunlight hours the interior temperature is higher than exterior temperature.

The figure 5 shows the measured solar radiation and the thermal radiation emitted to the sky. The average of received solar radiation is higher than emitted thermal radiation. The emitted is relatively low due to the Mediterranean Sea influence, because of meteorological reasons (dominant South component winds from the sea, in summer, and large evaporation of water). Relatively high humidity (near 67% with mean temperature near 26ºC) lowers the cooling radiation effect, because the opacity of water vapors to IR radiation. However, according to the measurements from the Pyrgeometer, it should be pointed out that even in this case, it is possible to emit near 100 W/m^2 to the sky.

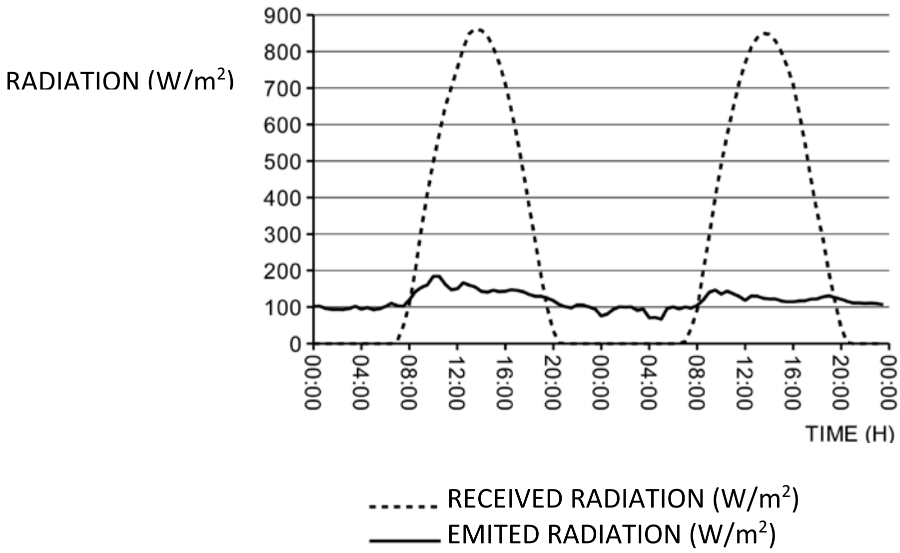

Figure 5 Dotted line shows global solar radiation on horizontal surface from meteorological station. Continuous line shows net IR radiation emitted to the sky from the Pyrgeometer

With the above data and the exterior temperature we computed a thermal balance equation for the interior of the model. We take into account the exterior air temperature, the thickness of the thermal insulation, the thermal radiation from the emitting surfaces, a heat transfer from the sun exposed sides of the model (surface temperature measured with a 66 IR Thermometer from FLUKE) and an approach to the diffuse radiation on the roof.

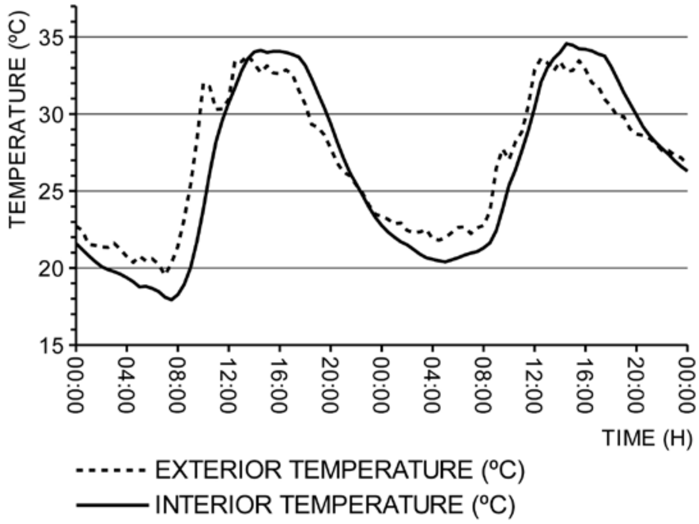

Figure 5 Dotted line shows the exterior temperature and continuos line the interior one.

The measured interior temperatures at 14h are no more than 0.3ºC different from those calculated by this approach. An excessive entrance of heat due to direct solar radiation incidence on the model area increases exterior surface temperatures. A high value of diffuse radiation conditions of Mediterranean summer sky also contributes to reduce the efficiency of this prototype as cooling device.

If solar protection had been applied to the lateral walls of the modular system, as it was done in the first model, the computation result would be 1.3 ºC lower. In this case, the interior temperature would be lower than external temperature during almost all day. Further on, an increase of roof thermal insulation in the parts which receive direct sunlight could have improved the results.

CONCLUSION

We consider two prototypes of radiative cooling roof. First one is a simple unit where the whole roof acts as IR emitting surface and lateral protections to direct sunlight are added. Second one is a modular design where the emitting surface is 1/6 of the roof area because of the integrated sunlight protections.

In both cases the space to be cooled was near 40x40x30 cm and was thermally insulated with at least 5 cm of expanded polystyrene except for the emitting surfaces.

First prototype was tested in Barcelona and the measured interior temperature was near 2ºC lower than exterior. This result is in agreement with a basic calculation taking into account heat transfer trough the walls and thermal emission from the roof. Exterior surfaces of the model were at exterior air temperature because they were protected from direct solar radiation.

In the second case the interior temperature was 2.5ºC lower than exterior only during night hours, while it was near 2.5ºC higher than temperature during some sunlight hours. This result can be understood because of solar gains through the sunlit walls and indirect solar radiation gains through the roof. The measured interior temperatures at 14h are no more than 0.3ºC different from those calculated by the thermal balance equation. If solar protection had been applied to the lateral walls of the modular system, as it was done in the first model, the result would have been better.

Summarizing, the possibilities of diurnal radiative cooling during summer in Mediterranean climate are mainly bounded by three factors. First of them is the relatively high humidity and low transparence of atmosphere to IR radiation. However, according to the measurements from the Pyrgeometer, it should be pointed out that it is possible to emit near 100 W/m^2 to the sky in our summer climate. Second one is the need to restrict, with an appropriate geometry, the aperture of the radiating system to the cold zone of the sky vault. And third factor is the absolute need to reduce the entrance of direct or diffuse solar radiation. Even with these bounds, we show that it is possible to obtain diurnal radiative cooling in sunny places by appropriate selection of geometry and easy to obtain materials.

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High Performance Landscapes – Reclaiming Lost "Ground"

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ABSTRACT

The rapidly urbanizing environment and resultant social and environmental impacts are far too complex and significant to limit problem-solving capacity to one discipline. Collaboration will become increasingly imperative in our increasingly dynamic world, yet despite the demands on designers, planners, engineers and developers; there remains a lack of collaboration and critical analysis on how we integrate the built environment within its larger context. Popular "green" building programs are increasingly being adopted for improving environmental impact on a project-by-project basis, focusing on building systems and materiality. However, ecosystems function on a landscape level and guidelines and design consideration at that spatial scale are lacking. The result is a landscape that is relegated to left over spaces. Despite their lack of attention, these interstitial, remnant exterior spaces in our growing cities can have meaningful contributions aesthetically, ecologically and socially and should be given more thought in the design process through collaboration.

To highlight the contributions these small spaces can make, a research project where ecosystem services (stormwater, habitat value, soil health and social implications) are measured and its application to a master plan for a sub-urban Greenfield Institutional site in Nairobi will be discussed. This design approach reflects the growing trend in landscape architecture, which focuses on "evidence-based" design (Brown and Corry, 2011). By measuring and monitoring the contributions a landscape can make, designers can fully engage the site to maximize its performance and create an integrated, interactive and adaptive relationship between people, buildings and their environment. These case studies will clarify the significant and once underestimated contributions that mechanically simple and biologically complex living systems above and below ground can make to stormwater management and habitat quality, and the social implications of these beautiful, legible and high-performance landscapes.

INTRODUCTION

Designing a landscape that maximizes ecosystem services, along with human health and well-being, requires the disciplines of natural sciences, architecture, urban design and landscape architecture to engage in research and outreach to support the amelioration of our urban environments through "evidence-based" design (Brown and Corry, 2011). Scientists and designers need to pursue rigorous research on designed systems to understand their contributions related to aesthetic and social values, and functional ecosystem services. Additionally, the research must not only look at designed landscape projects, but also at natural analogous systems for setting performance and sustainability benchmarks. When designing urban landscape spaces to maximize social, ecological, economic and aesthetic benefits, designers must set measurable goals.

This paper explores the growing yet relatively new field of performance-based landscapes, from design to post-occupancy research, within an urban context by focusing on The University of Pennsylvania's Shoemaker Green project. The preliminary findings from the data collections of this project has ratified the framework developed for quantifying the success of an integrated ecological design process; a process that has been crafted over the last five decades or so by the ecological design and planning community. Al Jamea Tus Saifiyah educational campus in Nairobi which adopted this integrated process in embedding environmental resiliency into the development of a greenfield Institutional site in Nairobi, can be a model for rapidly urbanizing cities across the globe. While the contexts of the two projects discussed here are vastly different, engaging in the reinvention and revitalization of the site through an understanding of its larger context and systems, remains an underlying consistent theme.

Figure 1 Two examples of landscapes that are benchmarks for providing ecosystem services: Sidwell Friends School in Washington D.C., where the constructed wetland becomes a "working landscape" using biological processes to clean grey and black water (left) and Phipps Conservatory in Pittsburgh which has achieved "living building challenge" rating (right). Both sites are currently being monitored for ecosystem services.

SHOEMAKER GREEN CASE STUDY

As a SITES[1] pilot project, the goals of the 2.75 acre Shoemaker Green project were to improve water, soil, vegetation, materials, human health and well-being in unison. Each component played a vital role in creating a healthy functioning ecological system. A monitoring plan (2012-2017) was established with the University to measure the performance of the site. The measurement was primarily focused on stormwater management performance through installed green infrastructure features that included sand filters, rain gardens, bio-swales, tree trenches and cisterns, etc. The goal of monitoring is intended to inform the SITES performance benchmarks, the City of Philadelphia and other regulatory entities such as the Environmental Protection Agency (EPA) that sets standards for environmental impacts of projects across the United States.

Figure 2 Shoemaker site plan and photograph of the site showing an event on the Green.

SHOEMAKER GREEN MONITORING PROTOCOL, PROJECT OBSERVATIONS AND PRELIMINARY FINDINGS

Establishing measurable goals requires a multidimensional investigation that involves observing comparable sites where these dimensions have been measured and by looking to analogous natural systems, which can serve as benchmarks for high performance. Understanding the interaction between abiotic and biotic parts of a landscape resulting in maximum performance and embedding resiliency in design that deals with unforeseen factors in unpredictable and harsh urban environments, becomes a quite daunting, but essential component of sustainable landscape design of urban spaces. Unfortunately, data on comparable landscapes that measure similar parameters is lacking, but reasonable amounts of information about performance of our natural systems are available.

The Shoemaker Green design team looked at one of the most high performing terrestrial models; the eastern deciduous forest, specifically the forests of the Delaware River Terrace and the Piedmont Upland Ecoregions; to inform the critical design components of the project's efficient, high performance landscapes. Given the specific issues relevant to the City of Philadelphia and the site's proximity to the City's river corridors, the focus of landscape performance was centered on stormwater management and habitat value. This inquiry required a comprehensive study of analogous forest characteristics--vegetation assemblages, soil structure, habitat creation and the possible human role in these systems. The monitoring program was structured to test the design hypotheses. As such, data related to stormwater, transpiration, soil, habitat diversity and social behavior were analyzed by scientifically accepted methods.

Stormwater Quantity and Quality- Every drop of rain water and a portion of air conditioning condensate from surrounding buildings is routed through a matrix of plants and soil and various conveyance systems, such as swales, trench drains and smart drains into a 20,000 gallon underground cistern (Figure 3). From May 2013 to September 2014, data shows that no stormwater has left the system to the combined sewer, including a 3.16-inch storm in June 2013 and 11 unusually wet months of the 14 month monitoring period. . Increased residence time (detention) within vegetated systems also allows more opportunity for water to be transpired and evaporated, which is especially beneficial in urban areas that are prone to heat island effect. On two occasions the system came close to overflowing on a dry day and a malfunctioning irrigation system was the key contributor (Figure 4). These findings allowed the facilities managers to adjust the irrigation program and modify it to be more efficient.

Figure 3 Stormwater features include a stormwater sand-based storage system under the Green (upper left and right), a rain garden (lower left) and a 20,000 gallon cistern (bottom right) for water reuse.

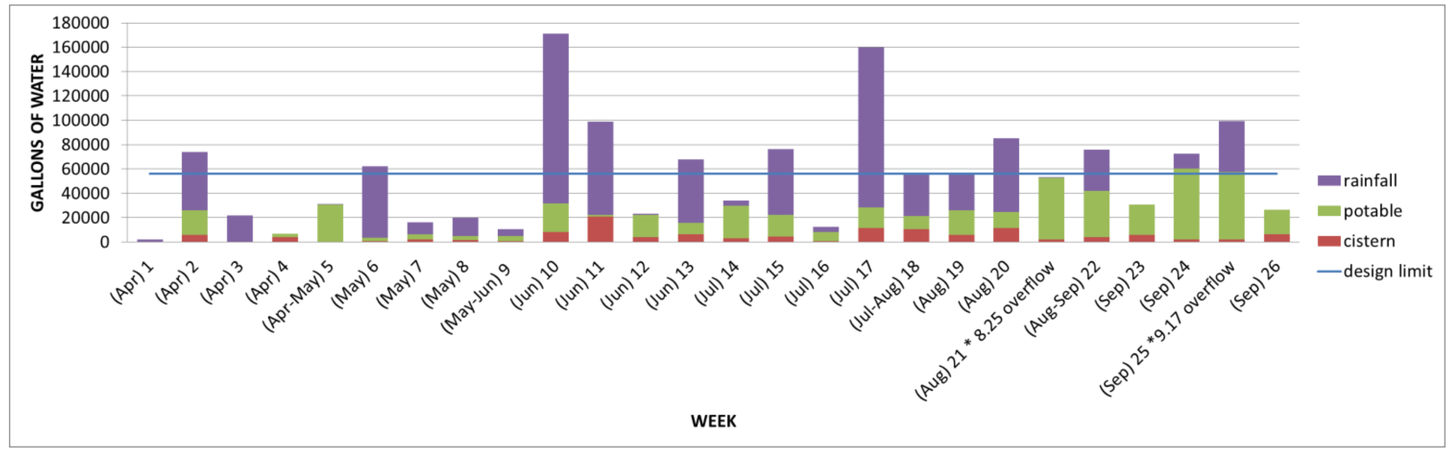

Figure 4 Irrigation use and rainfall data for 2013. Overflow to the combined sewer only happened twice.

Transpiration- Transpiration was monitored using leaf area index (LAI) values that were calculated with a linear photosynthetically active radiation (PAR) sensor and a leaf porometer. Data were gathered from trees, shrubs and groundcovers. The transpiration rates (E, mmol m−2 s−1) of leaves were calculated from the stomatal conductance and meteorological data gathered from the on-site weather station using Fick's law and the Penman – Monteith equation (Rahman et al., 2011). Preliminary results indicate strong transpiration rates from *Quercus phellos* and *Nyssa sylvatica* (Figure 5, left). A strong performance by the native floodplain species in the urban forest parallels that of the native forest studies, giving an insight into species that may be successful for transpiration within urban settings. (Beissel and Shear, 1997). This data was paired with soil evaporation measurements taken from the site's tensiometers to understand the water loss through evapotranspiration.

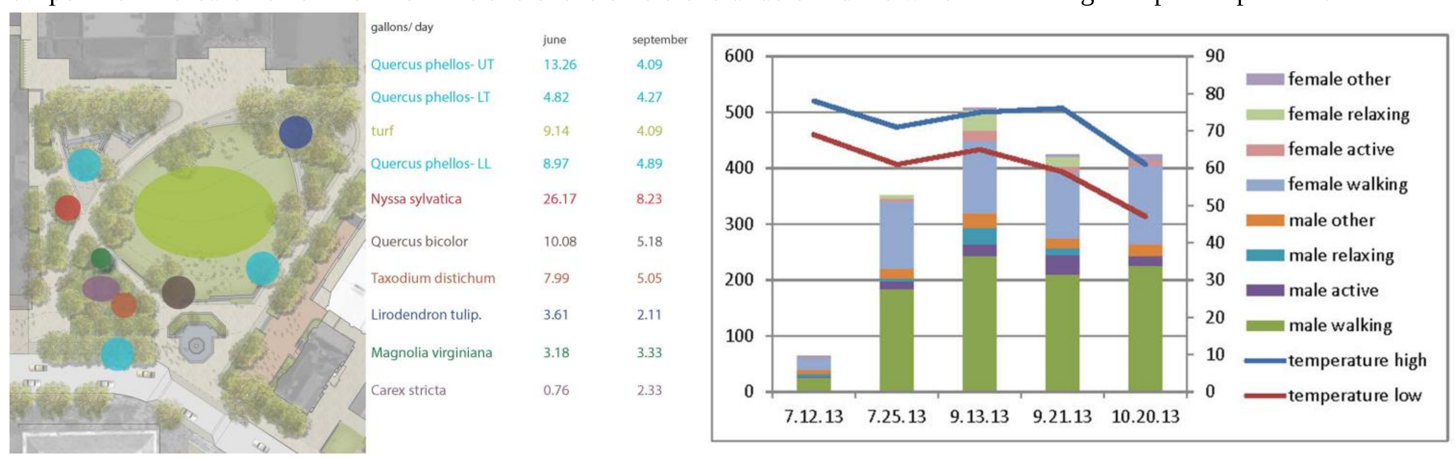

Figure 5 Transpiration rates of tree species taken over 3 different months in 2013 (left) and example of social mapping conducted July through September 2013 (right).

Soil- Preliminary data indicates microorganisms are present and the soils are developing organic matter to the desired levels suitable for different landscape types. However, compaction readings indicate that some areas of the lawn (four of the seven sampling points) are slowly approaching the 300psi threshold, which is the compaction rate when roots begin to resist penetration. In the rain garden, soil reports indicate a balanced fungal to bacteria ratio, a ratio expected in a landscape that supports healthy perennial grasses and understory trees; and few indicators of anaerobic conditions, suggesting that the rain garden is currently "drying out" between wet periods.

Habitat- One migratory species that is found regularly throughout shrubby thickets and woods, particularly along watercourses and in wetlands in North America is the yellow warbler, *Septophaga petechial*. The warbler, rarely found in urban settings, was spotted in the *Carex stricta* in the rain garden gleaning insects, suggesting the beginning of a diverse urban habitat. Other species identified include: Song Sparrow (visual ID), House Sparrow (visual ID) and a Wood Thrush (vocal ID).

Social Mapping- The social impact of the site is currently being studied through surveys and behavior mapping. The surveys were distributed to 200 randomly selected visitors in February, March and April of 2014. Visitor utilization was also documented via behavior mapping observation (Figure 5, right). From the surveys, it was evident that the extensive use of the space, as observed through each season, and the perceived value of the space, indicates an opportunity for education that can encourage an appreciation for urban ecological systems. Also, very early findings suggest that designed pathways were appropriately sized for the foot traffic and further analysis is needed to better understand the social implications of the project.

APPLICATION OF RESEARCH TO AL JAMEA TUS SAIFIYAH CAMPUS MASTER PLAN IN NAIROBI, KENYA

An ecological design approach and a collaborative process, one which carefully interweaves environmental and sustainable design principles, was adopted for planning the new Al Jamea Tus Saifiyah educational campus in Nairobi; a campus planned to reflect Fatemi cultural concepts, Fatemi philosophy, art and architecture, while utilizing state-of-the-art modern technologies and the latest educational thinking to provide enhanced ecosystem services. The Shoemaker Green research framework for monitoring the performance of the landscapes on the site has been used to develop a site specific ecosystem monitoring dashboard for the Jamea site. The monitoring program will measure microclimate benefits, irrigation use, stormwater volume and quality and species diversity on identified test plots within the nine acres of gardens and green roofs.

Figure 6 Site Plan of Al Jamea Tus Saifiyah Campus, Nairobi showing integration of buildings with open space.

Evaluating the context and site conditions, along with understanding the nature and ecology specific to the site, led to site specific solutions that will be sustainable over the long term. Close collaboration between the client and the design team helped achieve the goals of re-introducing biodiversity, enhancing the site's ecological systems, creating landscapes that are self-maintaining and more resilient to climate extremes, while using minimum energy and human capital. The confluence of ideas that emerged from the study of patterns of native analogous vegetation; the microtopography; flora and the fauna; the movement of the sun and temperature swings; wind and its seasonal changes; and the fluctuations in rainfall were useful in setting up a monitoring protocol for measuring the ecosystem services after the completion of construction in 2015.

Sustainable water features are integrated in the design to capture run-off and enhance campus microclimate. Runoff directed through plant beds, vegetated buffers and rain gardens improves water quality while reducing portable water use for irrigation. Heating and cooling effects of the green roof compared to the landscape at grade will be measured using sensors and heat transducers placed at all layers of the roofing, above the plants, and above the green roof area. Stormwater run-off volume and quantity overflow from the green roof, collected in the cisterns, and the volume leaving the site will be measured. Bordering the Nairobi National Park, the Site's context is characterized as semi-humid to semi-arid and offers an opportunity to extend the natural wildlife habitat by creating ecological corridors. Multi-layer native plant assemblages are re-introduced within the site based on lessons in ecological structure and diversity provided by the native plant communities. Biological monitoring involving study of species present including microbial activity, micro fauna and fauna will be recorded for a period of 2 years. Healthy Soils are essential to vigorous plant growth, effective stormwater management and reducing landscape maintenance. The soils on the site are deep, friable black cotton soils over rock which are flood prone, nutrient poor and have high shrink-swell capacity. The existing soil quality will be enhanced using borrowed fill from a neighboring construction site, incorporating mychorrhizae and compost from the on-site composting facility.

INFERENCES AND CONCLUSION

The preliminary results from the Shoemaker Green project and the other projects being currently monitored, are starting to provide a scientific backing to the hypothesis that landscapes and their biotic components provide critical ecosystem services, and that maintenance and monitoring are important for the long term sustainability of any project. Even a relatively small urban landscape, is capable of fulfilling multiple aesthetic, social and environmental roles. While there remains much more to learn from ongoing monitoring of Shoemaker and other projects, it is clear is that the success of the integrated design process is dependent on including maintenance and monitoring as a part of a comprehensive design of our landscapes. As designers we should collectively ask questions—ranging from investigations about the animals that pollinate and disperse the vegetation, to the mychorrhizae that help the trees and other vegetation manage stress and synthesize nutrients, and to the humans that care and maintain these spaces. Native and adapted plant communities that have adapted to unique environmental conditions and are surviving in dense urban scenarios can serve as models for setting the benchmark for ecosystem contribution. This exploration has tremendous applications in societies where the pressure of rapid development had the tendency to relegate landscape to left over spaces. Embedding resiliency and creating high performance landscapes, irrespective of size, is our opportunity to reclaim lost "ground".

ACKNOWLEDGMENTS

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FOOTNOTES

[1] Sustainable Sites Initiative (SITES), is an interdisciplinary program of the U.S. Botanic Garden, American Society of Landscape Architects and the Ladybird Johnson Wildflower Center. Similar to the LEED program, SITES establishes guidelines and performance benchmarks to enhance sustainability goals, primarily through an ecosystem services approach.

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Measurement of Thermal Radiation Properties of Large Heating Equipment Using Infrared Thermography

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ABSTRACT

Most modern houses no longer use traditional heating systems (e.g., the fireplace, stove, the pechka, the ondol, and the kotatsu) and instead rely on mechanical heaters, as the latter have greater functionality and more features. However, as the traditional systems use wood, a natural energy resource, they are more suitable for reducing the consumption of fossil fuels. Further, they provide a unique sensation of warmth as they dissipate heat through thermal radiation.

In this study, in order to reevaluate the heating characteristics of traditional heating systems that use wood, we devised a new method for measuring their thermal radiation properties. On the basis of the concept of the luminous intensity distribution, we defined the "thermal radiant intensity distribution," which is calculated by integrating the luminance of thermal radiation in each direction. A thermal image is constructed by assembling pixels representing the surface temperatures determined from a parallel projection of the heating equipment. Hence, the luminance of thermal radiation could be found for all the directions from the pixels to the observer.

We employed the proposed method to investigate a large firewood stove in operation in the winter, and determined its thermal radiant intensity, which was found to be 47–121 W/sr; this value is much greater than that of an electric heater (an 800 W electric heater has a thermal radiant intensity of 15 W/sr). It was assumed that, as traditional heating systems do not include a fan, larger systems are installed within the building structure and warm not only the air with the rooms but also the room surfaces, such as the walls, floors, and ceilings.

INTRODUCTION

In most modern houses, traditional heating equipment (e.g., the fireplace and stove in European countries, the *pechka* in Russia, the ondol in Korea, and the kotatsu in Japan) has been replaced by mechanical appliances such as air conditioners and fan heaters because of their better functionality and useful features. However, as traditional equipment use wood-based biomass, including firewood and wood charcoal, which are natural energy resources, they hold more potential in the near future from the view point of reducing fossil fuel use. Further, they also provide a unique sensation of warmth, owing to thermal radiation. For example, just after the Great East Japan Earthquake in 2011, firewood stoves were in high demand, especially in the arenas where the refugees lived for a few months in the winter season.

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The reason for this was not that the supply of other fuels was limited but rather that the heating capability of the stoves was better. It is for this reason that we have chosen to investigate the thermal radiation properties of traditional heating equipment.

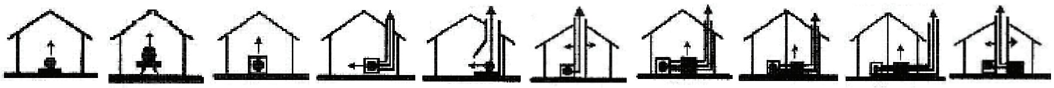
Figure 1 Firewood piled up under the eave of a traditional Japanese house.

1. EXOTHERMIC CHARACTERISTICS OF TRADITIONAL HEATING EQUIPMENT

Takamiya et al. have classified the heating equipment installed in vernacular architecture in Eurasia into Types #1 to #12 on the basis of their design characteristics, including factors such as whether the hearth is enclosed, where the exothermic part (i.e., the area, device, or unit from which the heat emitted) is located, whether it has a chimney, and what is its relation to the building. Developing this idea a little further, we have added the method of heat transfer to the classification system and reordered the types, deleting Types #6 and #7, as shown in Table 1.

With respect to the heating capability, Types #2 and #3 produce lower amounts of heat because these equipment pieces are "movable" and can be located in different places in the house, depending on the conditions. The "unified" types are graded from Type #1 to Type #12, that is, from "open" to "closed" on the enclosure of the hearth and "just around the hearth" to "dedicated part (in the next room)" on the exothermic part; these heaters are greater in size and have higher efficiencies. All the types except for Type #10 either do not have chimney or have an indoor one. Further, for all equipment types, heat transfer occurs through "radiation" or "conduction." Modern mechanical heaters, which are small and high-powered in comparison, distribute heat by blowing warm air in the room. As traditional heating systems do not include a fan, larger pieces of equipment are usually installed within the building structure to warm not only the air in the rooms but also the room surfaces, such as the walls, floors, and ceilings.

Table 1. Types and Characteristics of Heating Equipment

Type	#1	#2	#3	#5	#4	#8	#9	#11	#10	#12
										
Heater	Open hearth	Brazier	Kotatsu	Stove	Fire-place	*Pechka*	Kang	*Kachel-ofen*	Ondol	Kang
Enclosure of the hearth	<---- Open ---->		<--- Closed --->		Semi-Closed	<------------------- Closed ------------------->				
Part of the exothermic	<----------- Just around the hearth ----------->					Chim-ney	Dedi-cated part	Dedicated part in the next room		
Chimney	<--- Without chimney --->			<------------------- Indoors ------------------->					Out-doors	Indoors
Relation to building	Unified	<-- Movable -->		Fixed	<------------------------ Unified ------------------------>					
Method of heat transfer	<-- Radiation -->		Convection and Radiation		Radia-tion	Convec-tion and Radia-tion	<- Conduction ->		Convection, Radiation, and Conduction	

2. METHOD FOR EVALUATING THERMAL RADIATION PROPERTIES USING INFRARED THERMOGRAPHY

2.1 Thermal imaging

To determine the warmth-producing abilities of traditional pieces of heating equipment that make use of radiation and conduction rather than convection for heat transfer, as mentioned in Chapter 1, where the concept of luminous intensity (cd(= lm/sr)) distribution was described, we calculated their "thermal radiant intensity (W/sr) distributions." The thermal radiant intensity distribution of a heating system is a thermal radiation property and is obtained by integrating the luminance of thermal radiation (W/(sr m^2)) in every direction. The thermal radiant intensity for a specific direction is measured as follows:

1. Obtain thermal images using an infrared thermography system (i.e., a thermocamera) from a position at a specific distance from the center of the target heater. The nearer one is to the heater, the more detailed is the image obtained. However, if one is too near, the image will be distorted, in contrast to the image obtained from a parallel projection, because of the wide visual angle. However, it is difficult to keep the object distance large when photographing in the up/down directions. To ensure that the entire target heater was in the eyeshot of the thermocamera (horizontally 21.7° × vertically 16.4°) and to maintain the object distance at a reasonable value, we set it to 1.5 m.
2. Photograph the front side and in all the directions of the horizontal/vertical sides in steps of 22.5°. That is to say, photograph in 16 directions for each aspect, for a total of 41 directions (= (16 × 3) – 6 – 1), while excluding the 6 duplicated intersections and the upward view from below. If the shape of the heater is symmetric, it is enough to photograph 28 directions (= 41 – 1 – (3 × 4)).
3. Project the image of the concentric circles and radial lines on a wall of the room in which the photographs are being taken. Set the thermocamera at the intersection of these lines to pinpoint the object distance and the photography direction. We projected only one-fourth of the concentric circles (see Figure 2). Changing the top/bottom and the right/left directions allowed us to take photographs in limited space.

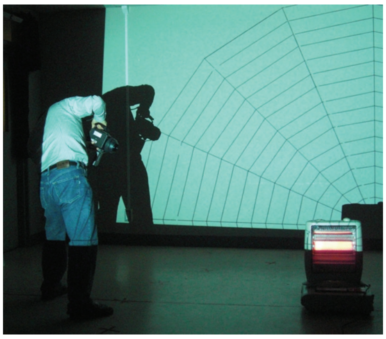


Figure 2 Procedure for obtaining the thermal image: the thermocamera is located at an object distance of 1.5 m; this can be confirmed from the shadow on the wall.

2.2 Calculating the thermal radiant intensity

If one considers a thermal image as a set of the surface temperature data that is the parallel projection of a heater, the thermal radiant intensity (W/sr) can be obtained by summing the luminance of the thermal radiation (W/(sr m^2)) from each pixel of the thermal image of the entire target heater to the observer, that is, in the direction normal to the thermal image (see Equation (1)). The denominator "2π" in Equation (1) represents the whole solid angle (sr) of the thermally imaged surface.

$$E = \sum_i \frac{\sigma T_i^4 S_i}{2\pi} \qquad (1)$$

3. MEASUREMENT OF THERMAL RADIATION PROPERTIES OF A LARGE FIREWOOD STOVE

3.1 Background for proposing a novel measurement method

The method described in Chapter 2 for measuring the thermal radiation properties has the following limitations:

1. It requires that the heater to be imaged be placed at a certain distance so that the entire heater fits in the eyeshot of the thermocamera.
2. The directions for which we can measure the thermal radiation properties using thermocamera are limited.

However, most traditional heating systems are large. Therefore, using this method, it is not possible to evaluate the thermal radiation properties in smaller houses as well as one can in the case of large houses.

3.2 From thermal imaging to thermal solid figures

Using the photogrammetry software "SurveyFromPhoto," it is possible to construct thermal solid figures from thermal images. We constructed thermal figures using bitmapped images with a 256-value palette. A heater and its thermal solid figure are shown in Figures 3 and 4, respectively. When constructing the thermal figures, the following four steps have to be followed, as per the specifications of SurveyFromPhoto. It should be noted that a thermal image has fewer pixels and colors than does an optical image. That is to say, it does not seem to have a third dimension.

1. The target can be photographed at any distance and from any direction and position. However, SurveyFromPhoto requires that each image has more than ten identity points. Further, among these, more than four of the identity points should be enclosed in several different images.
2. Before photographing the heater, place a piece of aluminum on any sharp edge or protrusion on the body of the heater so that its shape is visible and the identity points can be set with precision. Then, photograph the heater against a background of a different temperature.
3. Take photographs from each direction in front of the aluminum piece so that the identity points are distributed stereoscopically, as this will allow a precise solid figure to be constructed.
4. Take photographs from each direction in front of the major plane so that distortion-free images can be obtained to form the polygons that are used to construct the solid figure.


Figures 3 and 4 Photograph of the investigated electric heater (power of 800W) and its thermal solid figure.

3.3 Calculating the thermal radiant intensity

To calculate the thermal radiant intensity, Equation (1) can be used, provided the area of the pixels is determined as follows:

1. Push the PrtScn key on the keyboard when a thermal solid figure is displayed in the direction in which the thermal radiant intensity is to calculated, and open a copy of the image in the GNU Image Manipulation Program (GIMP).
2. Count the number of the pixels corresponding to the length of the reference line indicated in the image, and calculate the area of a single pixel (m^2) using Equation (2).
3. Erase all the pixels from the image, except those representing the target heater, either using the "fuzzy select" function of GIMP or manually (i.e., erase the pixels one by one), if necessary.
4. Save the image, which is now of only the target heater, in the BMP format and convert it to the CSV format using the software BMP2CSV, which allows one to change data formats.
5. Open the CSV file in Excel. The temperatures corresponding to the individual pixels can be found from the values in the spreadsheet and the color scale of the thermal image.

$$S = L^2 / N^2 \qquad (2)$$

3.4 Characteristics of the measurement method

When using the measurement method described in Chapter 2, the amount of thermal radiation emanating from the heating equipment is measured directly. Therefore, we can determine the actual values. On the other hand, in the case of the method described above, a thermal solid figure constructed using a software program is used as a virtual heater and is used for the measurements. Therefore, one can call the former method a direct one and the latter an indirect one.

The differences between the direct and indirect methods are listed in Table 2. The advantages of the indirect method are that the object distance and direction can be changed freely when taking the photographs. This makes it possible to photograph heaters in small rooms quickly. There are also a few disadvantages in than a number of different software programs are needed for the calculations. It should be noted that the distance for calculating the thermal radiant intensity, which is correlated to area of the pixels, is finite in the direct method, in which it is considered the object distance. On the other hand, it is infinite in the indirect method because the image constructed using SurveyFromPhoto is based on orthogonal projections. There is also a difference in the metric used to determine the size of the heating equipment. The solid angle (sr) is used in the direct method, while the projection area (m^2) is employed in the indirect method. Hence, it may be said that the two methods are quite different.

Table 2. Comparison of the direct and indirect measurement methods

Method	Direct	Indirect
Target for measuring thermal radiant intensity	Heating equipment	Thermal solid figure built using a software program and used as a virtual heater
Object distance	Distance at which the entire target heater fits in the eyeshot of the thermocamera	Actual distance, which depends on the space available in the room
Direction of photography	Direction of measurement	Actual direction for constructing the thermal solid figure
Software	NS9200 (NEC) Excel (Microsoft)	NS9200 (NEC) Excel (Microsoft) SurveyFromPhoto (Freeware) GIMP (Freeware) BMP2CSV (Freeware)

Distance for calculating the thermal radiant intensity	Finite	Infinite
Metric used to describe the size of the heating equipment	Solid angle	Projection area

3.5 Comparison of the results obtained using the direct and indirect methods

Figure 5 shows the thermal radiant intensities of the heater shown in Figure 3 as measured using the direct and indirect methods. The solid angle and thermal radiant intensity/solid angle ratio determined using the direct method, as well as the projection area and luminance of thermal radiation are also shown in the figure.

On comparing the thermal radiant intensity distributions obtained using the two methods, it was found that the distributions had similar shapes (oval) on the elevation side. However, the directions of the peaks on the sectional and horizontal sides were different. The maximum intensity was noticed in front of the heater, that is, at #13 in Figure 5, when using the direct method, while a gap of 22.5° or 45° existed when using the indirect method. This is because the grille and fire back do not affect the results obtained using the indirect method. That is to say, an exact heating element was not built in the virtual thermal solid figure but was represented by a thermal image plane instead. The difference in the thermal radiant intensities obtained using the two methods was less than 1.5 W/sr (i.e., 17%).

Further, on comparing the parallel values, that is, the thermal radiant intensity/solid angle ratio obtained using the direct method and the luminance of thermal radiation determined using the indirect method, the directions of the maximum/minimum values were similar. Thus, it can be surmised that the indirect method is suitable one.

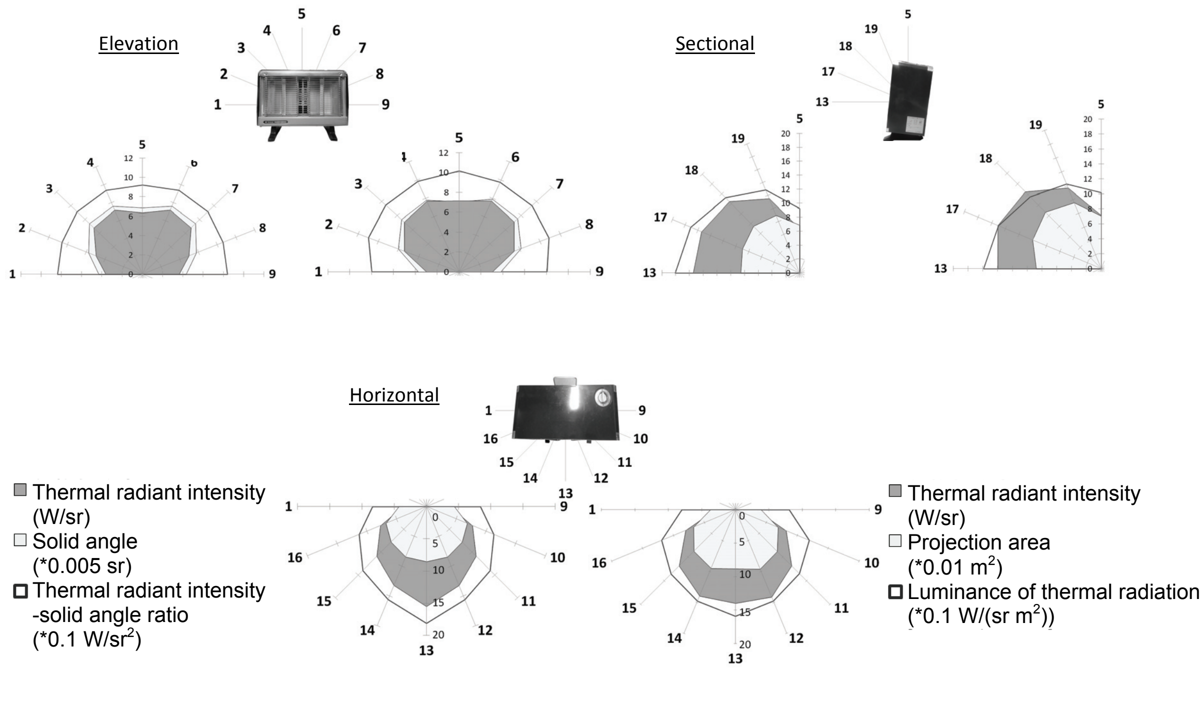
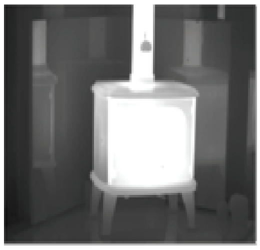


Figure 5 Comparison of the results obtained using the direct method (left) and the indirect method (right).

3.6 Thermal radiation properties of a large firewood stove

3.6.1 Measurement procedure. We employed the indirect method to measure the thermal radiation properties of a large firewood stove used routinely in the house. The target stove had a well-designed but complicated shape, as shown in Figure 6. The measurement was performed under the conditions listed in Table 3. Several kinds of air-dried firewood, such as Japanese cedar, cherry, sawtooth oak, and zelkova, to name a few, but not pine, were burned as per usual use. As can be seen from the thermal image in Figure 7, the surface temperature of almost the entire stove exceeded the upper limit of the range of the thermo camera (120 °C). Even though the stove was installed in a large room of a detached Japanese house, it was in a corner surrounded by houseplants and pieces of furniture. Therefore, the area that could be photographed was restricted.

3.6.2 Measurement results. The thermal radiant intensity, projection area, and luminance of thermal radiation of the large firewood stove are shown in Figure 8. The most important point to note is that the thermal radiant intensity was determined to be 47–121 W/sr, which is much greater than that of an electric heater (an 800 W electric heater exhibits a thermal radiant intensity of 15 W/sr). The main reason for this is that the entire surface of a stove is an exothermic area, and a large stove has a large area. Because the upper limit of the temperature range of the thermocamera was 120 °C, the thermal image obtained could not have indicated higher temperatures. However, if one assumes that the internal temperature of the stove was 200 °C, the thermal radiant intensity would be more than 2.1 times higher, as per Equation (1).



Figures 6 and 7 Photograph of the investigated large firewood stove (made of cast metal; width = 742 mm, thickness = 607 mm, and height = 797 mm; maximum power = 14.0 kW, as listed in the catalog) and one of its thermal images.

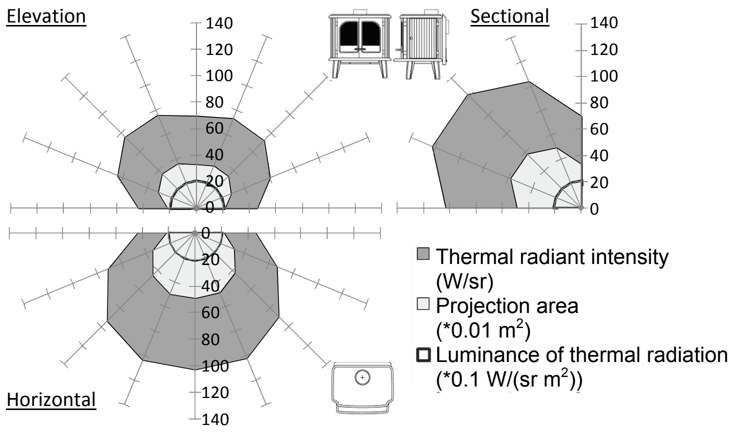


Figure 8 Thermal radiation characteristics of the large firewood stove.

Table 3. Measurement conditions

Date and time	Weather	Location	Indoor air temperature and relative humidity	Outdoor air temperature and relative humidity	Area of the room
Jan 26, 2011 10:30 AM to 12:00 PM	Fine	Detached house in Sendai, Japan	22.4 °C, 43% on average	6.2 °C, 42% on average	Main room with wellhole: 45.8 m^2

CONCLUSION

In this study, we proposed direct and indirect methods for measuring the thermal radiation properties of traditional heating equipment. Using the indirect method, we measured the thermal radiant intensity distribution of a large firewood stove and found that it radiated a large amount of thermal radiation. Shukuya has noted that *using radiant warm exergy for heating purposes is more effective than using convective warm exergy as the former results in both greater thermal comfort and a low human-body exergy consumption rate*. It is likely that the exergy consumption rate is a function of the quality of the warmth. The high thermal radiant intensity of the stove allowed it to not only warm the air in the room but also the room surfaces, such as the walls, floors, and ceilings. This probably accounts for the uniqueness of the warmth generated by traditional heating equipment. An exploration of type of walls and ceiling finishes should lead to a better understanding on how living spaces are heated through heat reflection/convection. We intend to pursue these goals in a future study.

ACKNOWLEDGEMENTS

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NOMENCLATURE

E = thermal radiant intensity (W/sr)
L = length of reference line (m)
N = number of pixels corresponding to the length of reference line
S = area of a pixel (m^2)
T = temperature of a pixel (K)
σ = Stefan-Boltzmann constant ($=5.67 \times 10^{-8}$) ($W/(m^2\ K^4)$)

Subscripts

i = pixel index number

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STRATEGIES TO ACHIEVE THE NZEB GOAL IN THE ENERGETIC REFURBISHMENT OF EXISTING BUILT HERITAGE. A CASE STUDY

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ABSTRACT HEADING

We report a case study on the conversion into a Nearly Zero Energy Building (NZEB) of an existing building, "The Visitors Centre for Nature Interpretation "located in the Pyrenees mountains of Catalonia, Spain. The original building was constructed in the last decade using strategies of passive and low energy buildings. At that time, there were no regulations about energetic certification in our country, and we have no reliable information about the energetic performance of many modern buildings theoretically considered as "low energy".

The research was carried out by collecting data on real consumption and CO2 emissions values and analysing both the energy systems and the passive conception of the building. Afterwards, our conclusions furnished information on which to choose the strategies aiming at the energetic refurbishment and the conversion into nearly NZEB of this public centre.

The main finding is that, by applying a combination of refurbishment options and improving the energy systems, a saving of approximately 50% is achievable in energy use and carbon emissions. Due the optimal levels of solar radiation in this place, the rest of the energy needed to afford the NZEB goal can be supplied by a photovoltaic installation placed on the roof. This approach can be applied to inspire and inform future reconversions of the existing modern buildings in Catalonia into NZEBs.

INTRODUCTION

The building sector is one of the productive sectors that needs to be acted upon if what is sought is a drastic reduction in CO_2 emissions. As such, adapting existing buildings to future energy requirements, as provided for in the EU's Energy Performance of Buildings Directive (2010/31/EU), is a challenge that must be addressed if we hope to deal with pressing issues of global warming and climate change. To achieve these objectives, the EU Directive urges Member States to ensure that as of 31 December 2020 all new buildings in the European Union (or 2018 in the case of public administration buildings) should satisfy nearly zero energy standards. Nearly zero energy buildings (NZEBs) can be defined briefly as buildings with a very high level of energy efficiency, whose very low energy requirements should be met by energy from renewable sources, so that the balance between energy consumption and energy production is zero. However the EU Directive says nothing about existing buildings, which constitute the majority of the built heritage in use, and it seems likely that in the EU, because of the economic crisis, very few new buildings will actually be built in the coming years. Therefore, the real challenge is how to address the energy performance of the existing built heritage.

This paper summarises the applied research carried out by our research unit in which the use of specific software tools is of great importance for verifying the performance of solutions developed, in the first instance, intuitively

INTENT AND OBJECTIVES OF THE APPLIED RESEARCH

The building analyzed in this case study is the Visitors Centre for Nature Interpretation located in Son, a small village in the Pyrenees mountains in Catalonia (Spain). It lies at latitude 42º 37' N, longitude 1º 05' E and at an altitude of 1540 m. Based on the Köppen climate classification, Son occupies climate zone Dfb, characterized by mild summers and severe winters receiving snow in winter and constant rainfall throughout the rest of the year, exceeding 750 mm per annum. Average annual temperatures range between minus 10 and 25 ºC, and relative humidity between 65 and 100% in the summer and between 80 and 100% the rest of the year. The solar insolation index is high at around 4211 Wh/m2day, average, with a predominance of light winds from the west and south-west all the year.

The building was constructed during the last decade using passive design strategies in a highly valued environmental site located on the edge of the Aigüestortes National Park (Fig. 1).

Based on data accumulated over the period of more than ten years in which the building has been in use, we performed a diagnosis of the existing building collating data on its energy consumption and emissions. Our study proposes a series of actions aimed at achieving the standards of low-energy buildings, maximizing the active use of renewable energy and enhancing comfort conditions. All in all, the actions seek to minimize the building's environmental impact and so contribute, in some small way, to the global reduction in greenhouse gas emissions. In short, we seek to transform the Visitors Center into a nearly zero energy building.

The measures we took can be categorized in three types, implemented as follows:

1. Minimizing energy demand by enhancing the building's energy performance: Increasing insulation, improving solar radiation control and natural lighting and exploiting enhanced ventilation for cooling in the summer.
2. Increasing energy efficiency and improving the building management systems.
3. Substituting conventional energy sources with renewable sources.

The subsequent economic evaluation enabled us to analyze the feasibility of these measures and their payback period.

.

EVALUATION OF THE PRESENT BUILDING

The main conclusions to be drawn from the bioclimatic and energetic analyses of the building can be summed up as follows:

- The building is poorly insulated, and have thermal bridges. The openings are simple with many air leakage.
- The openings in the building's eaves block solar radiation in the summer and boost solar uptake in winter, but do not avoid penetration during warmer spring and autumn days.
- The building's orientation and design protects it from the prevailing westerly winds and impede natural ventilation.
- The levels of natural lighting are poor in communal areas during the day (bathrooms and corridors) and the levels and distribution of natural lighting in spaces with large openings to the exterior are not homogenous.
- Poor natural lighting necessitates the use of artificial lighting in many areas and is responsible for high electricity consumption.
- The building requires some cooling loads which currently remain unsatisfied with either passive or active systems.
- The building uses propane gas as its primary energy source, which is responsible for its high CO_2 emissions.

The total energy consumption of the building has been summarised in Table 1.

Figure 1 The Visitors Centre for Nature Interpretation

Table 1. Monthly data for electricity consumption

Month	Electricity consumptiom	Month	Electricity consumption
January*	---------------	July	12830,13 kWh
February*	9064,00 kWh	August	14196,82 kWh
March	17310,92 kWh	September	11826,03 kWh
April	13955,56 kWh	October	14753,26 kWh
May	10086,99 kWh	November	14640,30 kWh
June	13132,75 kWh	December*	7660,42 kWh
TOTAL			139458,00 kWh

*The visitors centre is closed from December 15 to February 15

Table 2. Annual energy consumption and CO_2 emissions

Primary source	Annual energy consumption	Conversion in kWh	Annual emissions CO_2	
Electricity	136.829 kWh	136.829 kWh	0,25 kgCO2eq/kWh*	34,2 Tn
Electricity - Photovoltaic	2.629 kWh	2.629 kWh	0	0 Tn
Propane gas	23.314 kg	324.512 kWh	2,94 kgCO2eq/kg	68,5 Tn
Diesel	10.577 l	26.500 kWh	2,72 kgCO2eq/l	28,8 Tn
Solar Thermal	15.194 kWh	15.194 kWh	0	0 Tn
	TOTAL	**505.664 kWh**	**TOTAL**	**131,5 Tn**
	Ratio (kWh/m2year)	202	Ratio (kg/m2year)	53

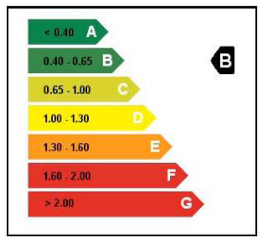
For assessing the CO_2 emissions, we have taken into account the annual energy consumption from different sources and emission coefficients per unit (Table 2)

ENERGY CERTIFICATION OF THE CURRENT BUILDING

A simulation was conducted with Leader and Calener software (Table 3) providing the following results: the building has a significant heating load (G) that can be attributed to the area's climatic conditions and a significant cooling load (C). Its CO2 emissions are average, being awarded a D, which is some way off the optimum level (A).
According to Spanish regulations the building's energy certification is graded as a B and the environmental conditions achieved inside the building must be: 23ºC - 25ºC temperature / 45% -60% relative humidity range in sumer and 21ªC-23ªC temperature / 40%-50% relative humidity range in winter.

Table 3. Energy certification

3. ETIQUETA Y VALORES TOTALES



Concepto	Edif. Objeto	Edif. Referencia
Energía Final (kWh/año)	944035.3	873494.6
Energía Final (kWh/(m²año))	624.6	577.9
En. Primaria (kWh/año)	1120637.1	2197904.5
En. Primaria (kWh/(m²año))	741.4	1454.2
Emisiones (kg CO2/año)	**239193.6**	**548868.9**
Emisiones (kg CO2/(m²año))	**158.3**	**363.1**

El consumo real de energía del edificio y sus emisiones de dióxido de carbono dependerán de la climatología y de las condiciones de operación y funcionamiento reales del edificio, entre otros factores.

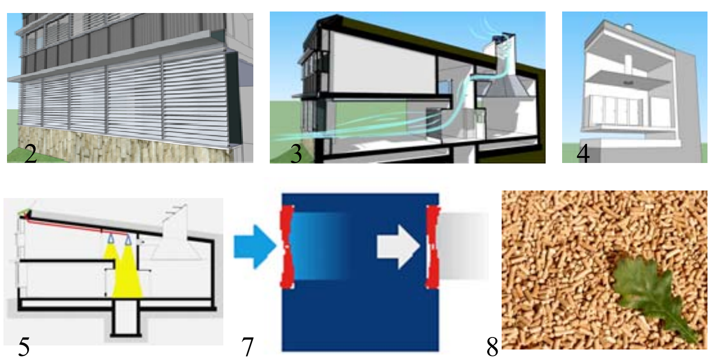
ACTION CHECK LIST

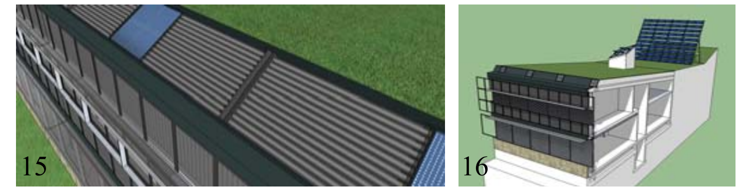
This section describes the actions planned to reduce the building energy consumption and achieve Nearly Zero Energy Building while improving indoor environmental quality. Will also detail the software tools that have been used for energy modeling.

Improvements employing passive strategies

1. Increasing wall insulation and replacement of existing windows by Higher-efficiency windows
2. Installation of motorized venetian blinds for protection from solar radiation on the south-facing façade (simulation with Ecotec)
3. Improving natural ventilation system for cooling in the summer (simulation with Phoenics)
4. Installation of highly efficient light tubes for channeling natural lighting into the bathrooms
5. Installation of a solar collector for channeling natural lighting in the corridors

Figure 2 Improvements



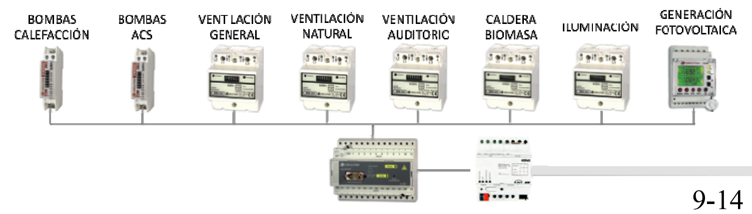


Improvements based on energy efficient systems

6. Optimization of artificial lighting by adjusting power installments (simulation with Dialux)
7. Installation of free cooling system in the auditorium
8. Replacement of gas boiler with a biomass boiler for heating and air conditioning

Enhancing the equipment of the building's management systems to increase energy efficiency

9. Control and regulation of blinds
10. Control and regulation of natural ventilation
11. Regulation system for lighting and light levels
12. Control and regulation of the free cooling system in the auditorium
13. System of measurement and monitoring of power consumption
14. System management of all the proposed services



9-14

Substitution of conventional energy sources with renewable sources

15. Production of air conditioning with solar thermal vacuum tubes, (48 modules, 62,48 m2. of catchment)
16. Electricity production using a photovoltaic installation on the roof, (78,75 kWp)

While it is evident that to increase energy efficiency of the building, the first action should be to improve the insulation, in some well-designed buildings of our modern built heritage like this one, specific constructive solutions to improve thermal performance of the building envelope are very difficult to implement, due to its high cost and the modification of its image. Therefore in this particular case study it was decided to use other strategies that do not damage the outward appearance and the interior finishes

ENERGY BALANCE

Among the different actions proposed we have included a new primary energy source, namely, biomass. Propane gas and diesel consumption has been virtually eliminated, limited now solely to the kitchen. We have not taken into consideration the fuel used in the electric generator as consumption is restricted to exceptional occasions (when there is a power outage) and so this does not form part of the building's normal operating conditions. The building's electricity consumption has undergone a significant reduction (in the order of 37%), which has considerably improved the ratio of energy consumed per square meter/year.

CO_2 EMISSIONS

Taking into account the reductions in consumption outlined in the previous section (and ignoring fuel consumption for the reasons presented above), the CO2 emissions can now be assessed. The electrical energy harvested from the photovoltaic system makes a negative contribution to CO2 emissions because it is clean energy fed into the grid, which helps improve the energy mix. This output also improves the ratio of energy consumed per square meter, as it offsets a significant proportion of the total, reducing the ratio from 202 kWh/m2 to 131 kWh/m2 year in the initial year of the proposed scenario.

Without taking the photovoltaic system into consideration, CO2 emissions are significantly reduced from an initial 302 tons/year to 131.5 tons/year, thanks to the marked reduction in the total amount of electricity consumption and virtual elimination of propane gas consumption. If we consider the total energy harvested from the photovoltaic system, we see this generates all the electricity consumed, thus enabling us to certify our building as a net zero energy building.

Energy consumption and CO2 emissions are summarized in Table 4.

Table 4. Final annual energy consumption and CO_2 emissions

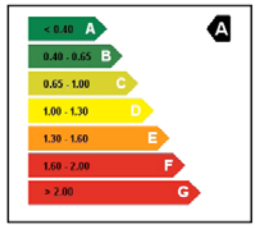
Primary source	Annual energy consumption	Conversion in kWh	Annual emissions CO_2	
Electricity	105.313 kWh	105.313 kWh	0,25 kgCO2eq/kWh*	20,3 Tn
Electricity - Photovoltaic	-119.640 kWh	-119.640 kWh	0,25 kgCO2eq/kWh*	-29,9 Tn
Gas propane	1.314 kg	1.290 kWh	2,94 kgCO2eq/kg	3,9 Tn
Biomass	80.213 kg	300.800 kWh	Balance neutral	0 Tn
Solar Thermal	38.913 kWh	38.913 kWh	0	0 Tn
	TOTAL	**326.676 kWh**	**TOTAL**	**0,3 Tn**
	Ratio (kWh/m2year)	131	Ratio (kg/m2year)	0

FINAL ENERGY CERTIFICATION

After implementing the above actions a new simulation was conducted with the Leader and Calener software providing the following results: improvements in the passive design mean that the load demand has been reduced by 10%. The use of energy efficient active systems and the harvesting of energy from renewable sources now ensure the provision of 100% of the uilding's requirements. In this respect, the building's initial D rating has been raised to an A.

Table 5. Final energy certification

3. ETIQUETA Y VALORES TOTALES



Concepto	Edif. Objeto	Edif. Referencia
Energía Final (kWh/año)	81346.2	810075.3
Energía Final (kWh/(m²año))	53.8	536.0
En. Primaria (kWh/año)	0.0	2053487.8
En. Primaria (kWh/(m²año))	0.0	1358.6
Emisiones (kg CO2/año)	**0.0**	**612624.5**
Emisiones (kg CO2/(m²año))	**0.0**	**339.2**

El consumo real de energía del edificio y sus emisiones de dióxido de carbono dependerán de la climatología y de las condiciones de operación y funcionamiento reales del edificio, entre otros factores.

Production of ACS using vacuum tubes also satisfies 100% of demand.

Improvements in artificial lighting mean the building's initial B rating has been raised to a final A rating. CO2 emissions have been reduced to a minimum. The building obtains a final A rating, recording optimum scores in all categories.

INFERENCES AND CONCLUSION

Table 6. Actions, quality improvements, saving and investment

Improvements	Annual quantitative improvements: Decrease emissions Tn CO2/year		Savings/year		Investment	
Louvers (installation and regulation)					114.217 €	14,5 %
Natural ventilation (installation and regulation)					103.420 €	13.2 %
Natural lighting bathrooms	0,18 Tn CO_2	0,2 %	110 €	0,2 %	5.018 €	0,6 %
Natural lighting hallways	3,65 Tn CO_2	3,3 %	2.187 €	3,9 %	67.811 €	8,6 %
Lighting (control and regulation)	13,46 Tn CO_2	12,2 %	8.078 €	14,3 %	23.518 €	3,0 %
Auditory cooling (installation and regulation)					39.170 €	5,0 %
Biomass Boiler	56,85 Tn CO_2	51,4 %	12.682 €	22,5%	39.865 €	5,1 %
Solar Thermal Energy	4,40 Tn CO_2	4,0 %	2.215 €	3,9 %	55.959 €	7,1 %
Photovoltaic energy	29,9 Tn CO_2	27,1 %	29.910 €	53,1 %	327.994 €	41,7 %
Electrical lines losses reduction	1,98 Tn CO_2	1,8 %	1.189 €	2,1 %	6.497 €	0,8 %
Electrical consumption measurement					2.729 €	0,3 %
Total	110,42 Tn CO_2	100 %	56.371 €	100 %	786.198 €	100 %

In a not too distant future, the progressive implementation of the Energy Performance of Buildings Directive in the building sector will lead a transition to the design of new buildings in which the energy concept constitutes a fundamental premise. This clearly represents a major challenge for architects, radically changing the way we design buildings.

This paper has made various contributions to this debate. In terms of methodology, it has stressed the importance of using specific software tools to verify the behavior of the solutions proposed. As shown with the corresponding architectural modifications, any existing building can achieve the nearly zero energy standards and produce its energy requirements from renewable sources in the building or in its surrounding environment. The building in our case study today generates 100% of its energy. This is a clear example of energy efficient architecture employing the tools of the bioclimatic design process. Active energy efficiency and the use of renewable energy sources are the way to shrink a building's carbon footprint.

Finally, we conclude that the most useful contributions of our applied research lie, first, in its ability to inspire and lead architects and engineers in the future energetic refurbishment of built heritage as they convert them into NZEBs. This proposal is a practical demonstration that sustainability is not an obstacle to design but rather a challenge to creativity. And, second, our proposal has the ability to revive those productive sectors suffering the effects of the current economic crisis. The example reported here should reduce resistance within the construction sector to adopt these principles, thereby allowing a successful theoretical concept to become a reality that can be accepted by the market and so generate renewed economic activity.

ACKNOWLEDGMENTS REFERENCES

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Phantom Loads in Residential Projects in Medellín, Colombia

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ABSTRACT

*Energy efficiency's specialized bibliographic sources define phantom loads as a dispensable electric energy inversion that some appliances make on secondary functions, such as light's pilots, remote control receptors and digital clocks. This investigation was developed in the "Laboratorio de Estudios y Experimentación Técnica en Arquitectura", LEET (Technical Experiments, of the Universidad Pontificia Bolivariana Architecture School, FAD-UPB). It proposes the verification, analysis and quantification of the phantom loads in residential buildings located on Medellin, Colombia, emphasizing on its origins based on the kind of appliances, its technologic validity and the use factor. The applied methodology on this investigation was based on energy consumption measurements during the stand-by mode of all the appliances of eleven similar socioeconomic condition residential buildings. A wattmeter was used as the main measurement tool. The results of this investigation revealed on quantitative data the impact of phantom loads over the total electric energy consumption bill of the analyzed buildings. Results also allowed classification of phantom loads according to how much the energy leak is, and its use. Consolidated data of this investigation prove that phantom loads are **3.73%** of the total electric consumption. This represents an opportunity of finding alternatives for an efficient management model of the cities electric consumption. This paper's conclusions are the first approach to the energy leaking problem in the national context.*

Keywords: *phantom loads, energy conservation, electricity, sustainable house.*

INTRODUCTION

Invention of the incandescent lamp in the year 1860 by English chemist Joseph Swan (*National Museum of American History*), defined the beginning of a process of colonization of households by technology that favored, during the following years, the invention of several electrical appliances, such as the telephone, the radio, the television set and the oven, among many others. During the decade of 1970, advances were carried out in the field of electronics: the personal computer was invented, as well as video games, cell phones and Internet. For all human needs that arose, a non-manual device was created to solve it, and that automatization process of daily household life known as automation, foresaw times of a high demand for electric energy.

Simultaneously to techonological advancement in the twentieth century, there emerged under the general ignorance, a phenomenon related to the electric energy consumption: "phantom loads" or "ghost loads". Since the invention of the remote control in 1903, some household electronic devices used it as the main command, which adaptation to radios and television sets required a new operational mode to

Author A is. Author B is.

use household devices, known as "stand-by" mode, by which the device has a percentage of electric energy to keep a receptor functioning, and allows it to be turned on at the order of the control.

The characteristics of households and the contemporary way of life, highly depending on electronic household devices, consolidated the set of phantom loads associated to each of the electric devices as a not negligible element on the monthly energetic budget. It is stated, according to studies carried out in the year 2000 in the main Australian cities *(Energy Efficient Strategies, 2006),* that the monthly average consumption by concept of phantom loads in Australian households was 86.8Wh per person, a figure that grew over a period of five years, reaching 10.7% of the monthly energetic consumption, that is to say, 92.2Wh per person, of a monthly average household total consumption of 265kWh.

The Colombian context, and specifically regarding the city of Medellin, Antioquia, still has no record of studies or measurements carried out with the goal of quantifying phantom loads and the calculations for its incidence within the monthly total electricity comsumption in residential buildings, for which this investigation applied to a specific context is considered pertinent.

THEORETICAL FRAMEWORK

The term "vampire Load" refers to the existing similitude between the fangs of the mythical character and the two common terminals in an outlet. There is no clarity as to whom and when this concept was first used to define power loss in household appliances during "stand-by" mode; however, it is attributed to swiss engineer Sandberg, E. (1993) the first use of the term *"Leaking Electricity"*, during the conference *"Electronic home equipment – Leaking electricity",* in Rungstedlund, Denmark, according to which an electricity leak is defined as: *"Energy demand of television sets, CD players and other electronic devises during inactive mode"*, making this a first approach to the concept of phantom load.

Nowadays, definition of the phantom load concept is directly related with modes in the use of electrical household appliances: off, in passive waiting mode, active waiting mode, and programmed start. Power consumption is not considered phantom load during active mode: *"standby consumption (or phantom) is the one generated while the household appliance is not performing its primary function". (Energy Efficient Strategies, 2006)*

METHODOLOGY

For the investigation purposes, eleven study cases were done in residential buildings in the city of Medellín, with area, typology, and population number variations, considering only the socio-economic levels 4, 5 and 6. The decision to collect this information in high economic levels is based on the presumption that the amount of household electronic appliances is greater per capita, thus increasing the possibilities of phantom load loss. Next there is a general description of study cases:

Table 1. General Information of each Study Case

Study cases general information						
Case No.	Population	Socio-economic level	Household appliances	Most recent monthly electricity consumption data (kWh)	Monthly phantom load electricity consumption (kWh)	Phantom load (%)
SC01	4	4	35	592,00	36,05	6,90%
SC02	3	4	21	249,00	9,21	3,70%
SC03	4	4	23	264,50	10,36	3,92%
SC04	1	4	8	99,00	5,83	5,66%
SC05	3	5	11	105,00	4,22	4,02%
SC06	3	4	33	216,00	12,16	5,63%
SC07	2	4	10	107,50	1,16	1,08%
SC08	3	6	13	161,00	1,23	0,77%
SC09	2	5	17	146,00	1,38	0,95%
SC10	1	4	9	128,50	1,74	1,35%
SC11	1	5	4	91,00	6,41	7,04%

Number of household appliances	184
Total population	27
Monthly electrical consumption per person (kWh)	79,98
Monthly electrical consumption per house (kWh)	196,32
Monthly phantom consumption per person (kWh)	3,32
Monthly phantom consumption per house (kWh)	8,16

Each study case consists of the measurement of electricity consumption of all electronic devices that remain connected to an energy source, during time intervals of: 0, 5, 10 and 20 minutes, which allows to obtain a weighted average consumption, and decrease this way the possibility of calculating irregular and/or atypical power consumption levels. The result of this operation expressed in Wh, is then multiplied by the number of **daily hours of dispensability** of the household appliance; that is to say, how many hours in a day such appliance could remain disconnected without affecting the lifestyle of the inhabitants, and that for practical issues was defined as 7, which represents daylight or night hours destined to sleeping, obtaining this way data for "Phantom/Day consumption (Wh)". Finally, column "Phantom/month consumption (Wh)" is shown, which is equivalent to multiplying the latter column by 30, the number of average days in a month.

In a simultaneous way to the application of measurements, other data was collected through observation and surveys, related to the characterization of each electric household device, an a greater understanding population habits, as well as the effective state of electrical devices. Additional data collected: **a)** category of use; that is to say, what is the purpose of the household device: computing, refrigeration and/or heating, entertainment, cooking, accessories or laundry; **b) brand** of the appliance, c) a brief **description** in case it is relevant, and finally, **d) approximate age** in years according to categories: 0 – 5 years old, 5 – 10 years old, 10 – 15 years old, and older than 15.

Table 2. Information Collection Table

Room	Household appliance	Category	Approximate age	Stand-by mode consumption (Wh)					Dispensability hours / Day	Phantom load / Day (Wh)	Phantom load / Month (Wh)
				Min 00	Min 5	Min 10	Min 20	Average			
Store	Telephone	Accesorio	1 - 5	0,00	0,00	0,00	0,00	0,000	7	0,000	0,000
	Common fridge	Cocina	1 - 5	0,00	0,00	0,00	0,00	0,000	7	0,000	0,000
	Postobón S.A Fridge	Cocina	10 - 15	0,00	0,00	0,00	0,00	0,000	7	0,000	0,000
	Ultraviolet lamp	Accesorio	10 - 15	0,00	0,00	0,00	0,00	0,000	7	0,000	0,000
	Microwafe	Cocina	10 - 15	138,00	139,00	138,00	134,00	137,250	7	960,750	28.822,500
	Coffee maker	Cocina	5 - 10	0,00	0,00	0,00	0,00	0,000	7	0,000	0,000
Garage	TV	Entretenimiento	10 - 15	0,30	0,30	0,30	0,30	0,300	7	2,100	63,000

For every residential complex, a survey was performed regarding people's habits, concerning topics related to electric savings that represent a percentage of incidence in the total phantom loads, such as finding out if people disconnect or not cell phones and personal computers when these devices are totally charged, and their willingness or not to modify their conduct once informed with respect to this issue.

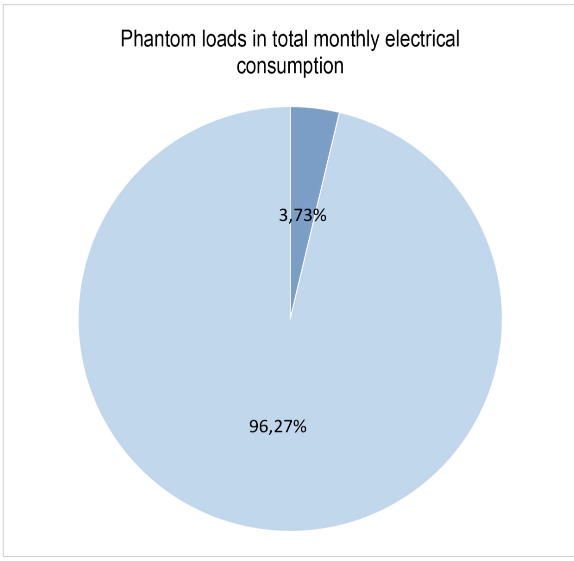
All measurements were done on a 20 minute time span for each device, through the use of a wattmeter called *Kill a Watt* with a precision range of 0.2%. Neither temperature nor humidity variations were considered at the moment of measurements, neither possible electrical fluctuations derived from the hour at which the electrical consumption was registered.

RESULTS ANALYSIS

- For the eleven study cases, **energy waste levels by way of phantom loads** are equivalent to **3.73%** of the total of monthly electric consumption for every household, which allows us to corroborate the existence of phantom loads in the urban residential sector in the city of Medellin. Next, the calculation of percentage representativeness of phantom loads in the monthly electric consumption, organized by study case and expressed in percentage:

Table 3. Calculation of Percentage Representativeness of Phantom Loads in the Total Monthly Electricity Consumption

Calculation of percentage representativeness of phantom loads in the total monthly electricity consumption		
Case No.	Phantom load (%)	Phantom loads average consumption (%)
SC01	6,90%	3,73%
SC02	3,70%	
SC03	3,92%	
SC04	5,66%	
SC05	4,02%	
SC06	5,63%	
SC07	1,08%	
SC08	0,77%	
SC09	0,95%	
SC10	1,35%	
SC11	7,04%	



Of all the study cases, SC08 showed the least percentage of incidences due to phantom loads, with a **0.77%,** and the SC11 the greatest, with a **7.04%.** The aforementioned are distant data from the average, because the majority of cases can be placed between **3** and **6%.**

- The analysis of **power consumption according to activity** shows that the greatest energy deviation is found in household appliances destined to Entertainment, with a **40.89%** of the total of electricity consumption by way of phantom loads, far from the second place taken by appliances related to Computation, with a **23.59%.** The activity that represented the least power expenditure due to phantom loads was Refrigeration/heating, with **0.43%,** due mainly to conditions of humidity and temperature in Medellin being close to thermal comfort range, reason for which these household electronic appliances are not commonly found for residential use.

Table 4. Calculation of Phantom Consumption According to Activity Type Related to Household Appliance

Calculation of phantom loads according to the type of activity related to appliance												
Usage categories	Percentage equivalent											Weighted average (%)
	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	
Accessory	6,64%	6,13%	27,76%	0,00%	0,00%	17,17%	0,00%	27,23%	60,52%	32,06%	6,56%	16,73%
Refrigeration/heating	0,89%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	3,88%	0,00%	0,00%	0,43%
Computation	7,70%	4,74%	24,57%	21,80%	10,69%	6,44%	0,00%	27,23%	20,71%	58,78%	76,80%	23,59%
Entertainment	4,82%	86,34%	41,80%	60,81%	85,07%	72,51%	12,22%	45,53%	14,89%	9,16%	16,64%	40,89%
Laundry	0,00%	0,00%	2,45%	6,58%	0,00%	0,00%	22,62%	0,00%	0,00%	0,00%	0,00%	2,88%
Kitchen	79,95%	2,79%	3,43%	10,81%	4,24%	3,87%	65,16%	0,00%	0,00%	0,00%	0,00%	15,48%

- Analysis of **electricity consumption according to age of household appliances** allowed investigating about the relevance of the "technological life" variable; in other words, incidence of age and the degree of technological update on energetic waste loads. Next, a graph that relates age to phantom consumption of household appliances:

Table 5. Age of household appliances and average consumption according to age

Appliances age and average consumption according to age												
Age of appliance (in years)	Average electricity consumption (Wh)											Weighted average (Wh)
	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	
1 - 5	1,26	3,48	2,28	3,70	0,00	1,87	0,21	0,30	0,52	1,25	12,71	2,51
5 - 10	0,79	0,72	1,24	2,76	3,28	1,10	1,07	0,63	0,67	1,10	0,00	1,21
10 - 15	23,04	0,00	5,55	0,00	1,18	3,82	0,00	0,73	0,09	0,00	2,54	3,36
>15	1,50	0,00	0,00	0,00	2,88	0,70	0,00	0,00	0,00	0,00	0,00	0,46

The average consumption in Wh of household appliances according to approximate age indicates that those that are between 10-15 years old have an average phantom consumption equivalent to 3.36Wh, the highest among analyzed appliances; however, consumption of those that are over 15 years old is only 0.46Wh; that is to say that, according to general performance, it is possible to state that there is no direct relationship between age and phantom load consumption, which allows to say that technological update of household appliances does not necessarily imply a decrease in phantom loads

- Another analysis item in this investigation seeks to establish what percentage of household appliances have electricity leakage in their secondary functioning modes, and simultaneously establish levels according to leak energy quantity. Established ranges for this analysis were: equal to 0Wh, less than 1Wh, between 1-5Wh, and more than 5Wh.

Table 6. Classification of Phantom Loads According Electrical Consumption

Classification of phantom loads according to electricity consumption												
Electricity consumption (Wh)	Equivalent percentage (%)											Weighted average (%)
	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	
Equal to 0	45,71%	28,57%	17,39%	12,50%	18,18%	42,42%	70,00%	38,46%	41,18%	33,33%	25,00%	33,89%
Less than 1W	22,86%	23,81%	21,74%	0,00%	9,09%	12,12%	10,00%	46,15%	41,18%	33,33%	0,00%	20,03%
Between 1 - 5W	22,86%	28,57%	43,48%	62,50%	45,45%	30,30%	20,00%	15,38%	17,65%	22,22%	25,00%	30,31%
More than 5W	8,57%	19,05%	17,39%	25,00%	27,27%	15,15%	0,00%	0,00%	0,00%	11,11%	50,00%	15,78%

Results according to the eleven study cases indicate that 33.89% of diagnosed household appliances did not have phantom loads, namely, electric consumption during secondary use mode is equal to 0Wh. Next, the graph summarizing classification previously mentioned:

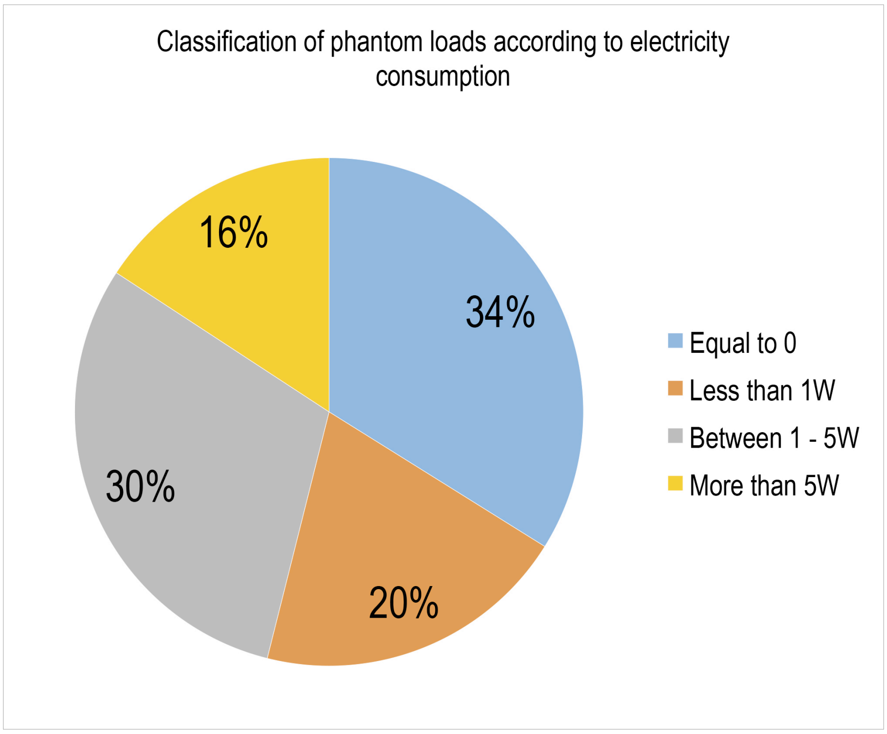


Figure 1. Classification of phantom loads according to electricity consumption

- According to statistics of the Mayor's Office of Medellín, in 2010 there were a total of 641,780 residential units in the city of Medellín. Extrapolating results from this investigation from the phantom loads data per household unit equivalent to 8.16kWh, means affirming that for the city's total households, the monthly electricity leakage is equivalent to **5,236,924.8kWh.**

Table 7. Number of households per Socio-Economic Stratum and Commune

Number of households per socio-economic stratum and commune								
No.	Commune	Socio-economic stratum						Total commune
		1	2	3	4	5	6	
1	Popular	13.106	22.870	16	0	0	0	35.992
2	Santa Cruz	4.022	25.419	8	0	0	0	29.449
3	Manrique	11.356	27.284	7.065	0	0	0	45.705
4	Aranjuez	4.043	14.223	22.532	15	0	0	40.813
5	Castilla	364	5.145	29.853	542	0	0	35.904
6	Doce de Octubre	7.042	27.464	12.435	0	0	0	46.941
7	Robledo	5.010	23.659	13.846	4.189	405	3	47.112
8	Villa Hermosa	14.809	17.079	10.634	887	0	0	43.409
9	Buenos Aires	1.474	11.030	26.444	3.956	491	286	43.681
10	La Candelaria	1	2.136	9.378	14.565	894	1	26.975
11	Laureles Estadio	0	63	353	13.676	25.250	0	39.342
12	La América	0	635	9.307	13.253	7.701	0	30.896
13	San Javier	17.010	18.643	10.289	2.469	0	0	48.411
14	El Poblado	16	687	611	1.546	7.638	30.058	40.556
15	Guayabal	100	3.415	11.283	5.268	0	0	20.066
16	Belén	1.210	11.521	23.978	15.742	14.076	1	66.528
Total x stratum		79.563	211.273	188.032	76.108	56.455	30.349	
Household per stratum (%)		12,40	32,92	29,30	11,86	8,80	4,73	
Total household		641.780						

The cost of that wasted energy is COP $ 2,038,858,872 million pesos monthly, according to the cost of 1 kWh as of January 2014. Data, discriminated by stratum, is shown next:

Table 8. Cost of Wasted Energy due to Phantom Loads According to Stratum

Cost of wasted energy due to phantom loads according to stratum				
Socio-economic stratum	Number of households	Monthly phantom consumption (kWh)	Cost kWh	Cost phantom loads consumption COP $
Stratum 1	79.563	8,16	379,07	$246.105.163
Stratum 2	211.273	8,16	379,07	$653.512.010
Stratum 3	188.032	8,16	379,07	$581.622.688
Stratum 4	76.108	8,16	379,07	$235.418.118
Stratum 5	56.455	8,16	454,88	$209.550.843
Stratum 6	30.349	8,16	454,88	$112.650.049
			Total	$2.038.858.872

- Based on results of the survey made to one person per household about some habits and their influence on phantom loads, results indicate that 63% of those interviewed decide not to disconnect their laptops from electricity once they are completely charged, and 90% decide not to disconnect their desktops when they finish using them. However, the survey indicates that 55% of those interviewed in fact disconnect their household electrical appliances at night, or during their absence during the day.

Table 9. Results survey made to a resident per residential unit

Results survey made to a resident per residential unit													
Questions	Casos de estudio											Yes	No
	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11		
Do you disconnect your laptop charger once the device has been fully charged?	No	No	No	Sí	Sí	No	No	Sí	Sí	No	No	4 36,36%	7 63,64%
Do you disconnect your desktop once you're donde using it?	No	No	No	No	Sí	No	No	No	No	No	No	1 9,09%	10 90,91%
Do you disconnect your household appliances during the night or when you are absent during the day?	Sí	Sí	Sí	Sí	No	No	No	Sí	No	No	No	5 45,45%	6 54,55%
Assuming that important household appliances such as the fridge, surveillance and security systems, and at least one telephone were to remain turned on and functioning, would you be wiling to disconnect all your household appliances if there was an automatic mechanism that did it for you?	Sí	Sí	Sí	Sí	Sí	Sí	Sí	Sí	Sí	Sí	Sí	11 100,00%	0 0,00%

The results of the survey show that, even though there is a degree of ignorance about the levels of electrical consumption during secondary functioning modes in some devices, and that the majority of the people do not disconnect electrical devices when done using them due to laziness or lack of knowledge, there is a high degree of acceptance to the proposal of solution alternatives that take care of disconnecting electronic appliances automatically, as is proposed in the last question of the survey, to which 100% of those surveyed answered in an affirmative way.

CONCLUSIONS

According to set objectives for the development of this investigation, this has been achieved:

- Demonstrating the existence of phantom loads in the urban residential sector of the city of Medellín, Colombia, according to analysis of electricity consumption made in eleven residential units with stratum 4, 5 and 6.

- Quantifying percentage incidence of phantom loads cunsumption over the total electricity consumption of diagnosed households, equivalent to **3.73%** of the monthly electricity consumption; that is to say, an average of **8.16kWh** per house.

- Establishing independence between phantom loads and technological update expressed in age and technological updating of appliances, through quantitative demonstration that there is no relationship between both variables.

- Quantifying economic and energy investment at a city level (Medellín) that represents loss of electricity by way of phantom loads in residential units, equivalent to **5,236,924.8kWh** and **COP $2,038,858,872** million pesos.

ACKNOWLEDGMENTS

The development of this investigation was possible thanks to the participation of Architecture students of Universidad Pontificia Bolivariana, Juan Camilo Paniagua, Mateo Alzate, Juan Camilo Fernández and Valerie López, who were active members in collecting information of every study case. Also thanks to the people who allowed student access to all rooms in their households with the goal of making all pertinent measurements.

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Renewable Energy Application in Floating Architecture

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ABSTRACT

Climate change like global warming brings sea and river level rise. Usable land in urban area becomes less and the price of real estate increases due to continuous development. Reclamation method for land supply has been regarded as environmentally negative. And people want to enjoy the life on water rather than on land or mountain according the improved income level. Therefore floating architecture on water has been emerging as a creative and alternative to the building on the land of waterside region. The aim of this study is to investigate the status of renewable energy applications in sample floating architectures and to suggest some reference ideas for new building projects around the waterside. Most popular renewable energy sources for the floating architecture are solar heat energy, solar photovoltaic energy and hydrothermal energy. Especially hydrothermal use of the water underneath the floating building may have a huge advantage in tropical region and cold region because there is a great temperature difference between the water and the outdoor air in extreme climate regions. Therefore hydrothermal energy can be used for air-conditioning in tropical region and heating in the cold region. Wind energy also can enhance the possibility of self-supporting floating architecture if building intergrated samall wind turbine with little noise is developed. Hybrid system of solar photovoltaic energy with wind power will be highly popular when the design of the hybrid system is intergrated with that of floating architecture. Of course, detailed disadvantages of floating architectures should be investigated and countermeasures to overcome are to be suggested for further study.

INTRODUCTION

Climate change like global warming atmosphere brings a rise in sea and river level. Usable land in urban area will be less and the price of real estate is going to rise due to continuous expanding development. Reclamation method for new land supply is regarded as environmentally negative and very difficult to proceed without the public consensus. People like to live and enjoy leisure activities near or on water according to the improved income level. New floating buildings such as house, restaurant, school, exhibition and meeting, yacht club house, hotel, ferry terminal, prison, and café are being built around the world. Therefore floating architecture on water has been emerging as a feasible and strong alternative.

Floating building is easy to get various renewable energy sources because there are not so many physical obstacles in the sea or river. More solar and wind energies can be obtained on the water than on the urban land. Especially hydrothermal use of sea or river water beneath the floating building might be a great advantage because the temperature of water is usually lower than that of outdoor air in summer and the reverse in winter. Therefore hydrothermal energy can be used as cooling in tropical region and heating in the cold region.

Floating Building can be generally regarded as positive in ecosystem because the building has a closed premises services system, sometimes stimulates diversity in water milieus and provides a protected habitats for small fish and other aquatic animals. The underside of floating building foundation can even be rough to encourage the attachment and growth of water plants, algae and shellfish. The water plants have a purifying effect on the water (Koen Olthuis & David Keuning, 2010). A large-scale floating architecture or a number of floating buildings can be criticised as throwing a shadow to the bottom of the water, so some countermeasure for the passage to give the sunlight to the bottom of the water should be considered.

The aim of this study is to review the concept of floating architecture and renewable energy in architecture, to investigate the renewable energy applications in planned and realized floating architectures, and to suggest some reference ideas for new building projects around waterside. Research method includes the navigation of related websites, site-visits, and the review of reference documents and literatures. Sample floating architectures with strong points of renewable energy applications are chosen to analyze.

FLOATING ARCHITECTURE

As the advantageous points of floating homes have been known to public, the new residents with interesting have rebuilt the new and luxurious floating homes replacing the old and poor ones in San Francisco and Seattle, USA. In Portland, USA, a large number of modern and large loating homes have been built on the Willamette River and near net zero energy floating home with solar PV system, solar water heating, hydronic heating, rainwater collection and reuse, and reclaimed and certified wood has been built in the North Portland's Tomahawk Island Floating Home Community. In Steigereiland IJburg, Amsterdam, Netherlands, there are 75 floating homes consisting of detached and row houses. So floating architecture becomes popular and familiar with the ordinary person.

Figure 1 Floating Homes in Seattle, USA(left) and Portland, USA(right)
(Source: photos by the author, 2012)

Floating architecture can be defined as a building for living or working space that floats on the water with floatation system, is moored in a permanent location, does not include a water craft designed or intended for navigation, and has a premises services (electricity, water/sewage, gas) system served through connection by permanant supply/return system between floating building and a service station on land, or has self-supporting service facilities for itself.

RENEWABLE ENERGY IN ARCHITECTURE

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water or space heating, motor fuels, and rural (off-grid) energy services (Renewable energy, Wikipedia, 2014).

In architecture, wind power, solar energy and geothermal energy in renewable technologies are generally being applied in the design and practice. Especially various applications of solar energy through solar heat panel and solar photovoltaic (PV) cells, and hydrothermal energy like geothermal energy are usually introduced in floating architectures on water.

Wind power, tidal power and wave power can be considerable if there is proper system to be intergrated with floating architecture and to be harmonized with the natural environment. Wind power is highly expected to be used in floating architecture because wind power resource is abundant on water space and small wind power turbine for the building is under development.

Hybrid system of solar energy with wind power will be useful and complementary because the sun usually shines when there is no wind in day time and the wind usually rises when there is no sun. So solar - wind hybrid renewable energy system will be popular when the design of the hybrid system can be intergrated with that of floating architecture.

PLANNED FLOATING ARCHITECTURE

Floating Mosque, Dubai (2007)

The floating mosque has modern and traditional Islamic designs. The interior is characterized by giant funnel-shaped transparant columns that do not only support the roof, but also allow filtered light to illuminate the inner space (Waterstudio, 2014). The building has 1 storey superstructure and the large pontoon made of concrete and styro-foam, and basically connects the water supply/return lines from the station of inland. But the building is designed self-supporting as possible in terms of energy.

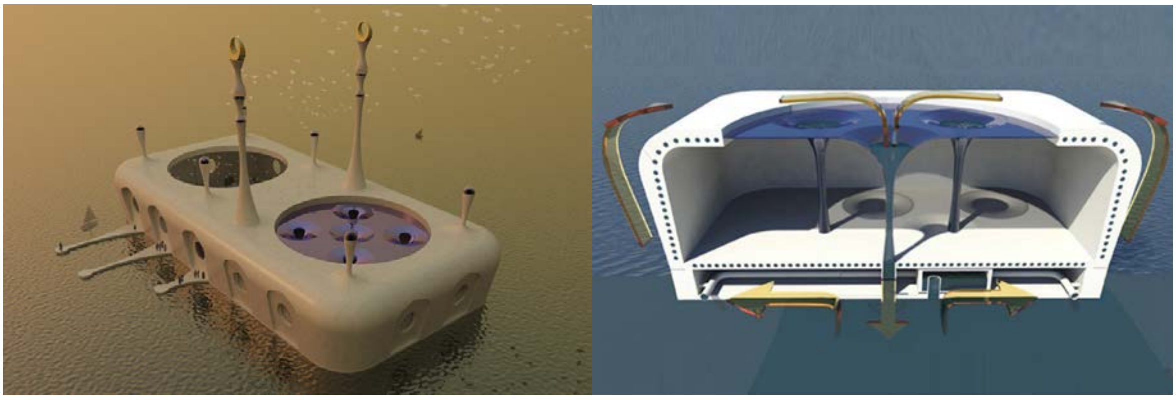

Figure 2 Model of Floating Mosque (left) and Water Cooling System (right)
(Source: http://www.waterstudio.nl/ projects/30, 2014)

The flat-roofed floating mosque is environmentally friendly by using the hydrothermal temperature, pumping sea water from the Arabian Gulf through a vein-like system of wall and floor cools the building structure down by 15 degree Celsius(from 45 degree to 30 degree), reducing the cost of cooling by around 40 percentage. Air conditioning by the electricity from solar photovoltaic cells brings the temperature down even further to 21 degree Celsius. Electricity from solar energy is also required for the pumping machine (James Reinl, 2007).

The roof and walls absorb little heat because of porous external cladding, consisting of a sponge-like ceramic material with extremely low density. The thick external walls have a high accumulative capacity due to their high density and large size (Koen Olthuis & David Keuning, 2010). Therefore, water cooling system can be more effective than any other measure.

The Ark (2010)

A massive dome-shaped building concept with living space of around 14,000 square meters, the Ark, is proposed to get maintenance of security and precaution against extreme environmental conditions and climate change together with protection of natural environment from human activities. The arch-shaped building has a structure that enables it to float safely and stay autonomously on the surface of the water. The Ark was also designed to be a bioclimatic building with independent life-supporting systems, including elements ensuring a closed-functioning cycle (Alison Furuto, 2011).

The Ark concept, designed with the UIArchitects Work Program “Architecture for Disaster Relief,” could be realized in various climates and especially in seismically dangerous regions because its basement is a shell structure without any ledges or angles. A load-bearing system of arches and cables allows weight redistribution along the entire corpus in case of an earthquake. And also its prefabricated frame can allow for fast construction (Anastasia Vdovenko, 2014).

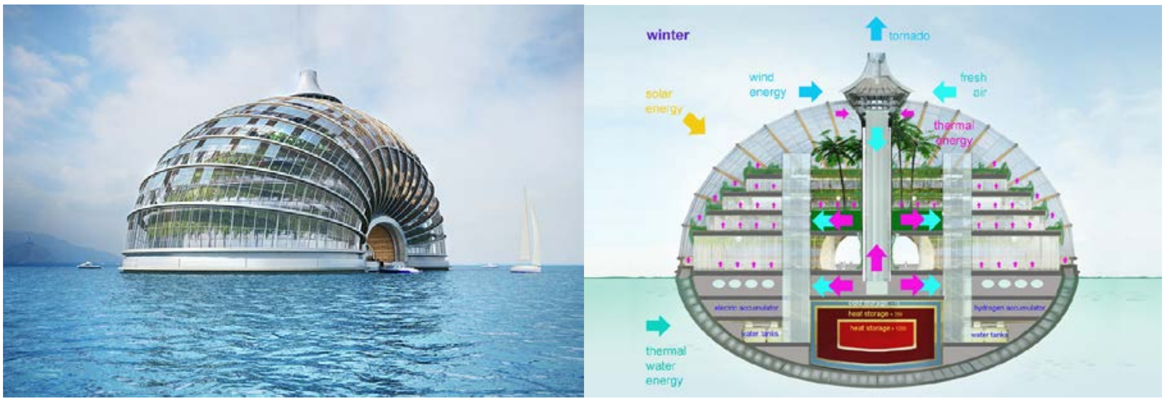

Figure 3 Perspective (left) and Section Diagram (right) of The Ark
(Source: http://remistudio.ru/en/pages/52.htm. 2014)

The building has an optimal relationship between its volume and its outer surface, significantly saving materials and providing energy efficiency. Its shape is convenient for installing solar photovoltaic cells at an optimal angle toward the sun and wind turbine on the roof.

The cupola, in the upper part, collects warm air which is gathered in seasonal heat accumulator to provide an uninterrupted energy supply for the whole building complex independently from outer climate conditions in winter. The heat energy from the surrounding environment - the outer air, water or ground - is also used.

The structural solidity is provided by compression of timber arches and tension of steel cables. The framework is covered by a special foil made of EthylTetraFluoroEthylene(ETFE). It is a strong, highly transparent foil that is self-cleaning, recyclable, and more durable, cost-efficient and lighter than glass. The foil itself is affixed to the framework by special metal profiles, which serve as solar energy collectors for heating water and as gutters for collecting rainwater from the roof (ARK, 2014).

REALIZED FLOATING ARCHITECTURE

IBA Dock, Germany (2009)

In 2010, the international building exhibition IBA had a slogan “City in a Climate Change” with a goal of a CO_2-neutral city development. The IBA Dock as the information and event center of Hamburg is constructed upon a floating pontoon. The building is now being used for Urban and Architecture information center in Hamburg and also the 2013 Hamburg International Gardening Exhibition. The IBA Dock not only houses the exhibition IBA, but is also itself an exhibition of innovative building and integrates numerous renewable energy technologies (IBA DOCK, 2014).

The IBA Dock has 3 storeys and 1,640 square meters floor area. The building is situated on an approximately 43m long and 26m wide concrete substructure pontoon and the superstructures of building are made of steel in prefabricated modular construction (IBA Dock/Architech, 2012). The building is setting new standards in the area of climate protection. In addition to 25cm thick insulated outer walls, the IBA Dock uses the sun and water of the Elbe for generating energy.

The building is based on “zero balance concept”, which focuses on solar energy management and systems that provide buildings with sustainable heat and cooling all year round. 16 rooftop solar heat panels with a total surface area of about 34 square meters are positioned facing south at the relatively steep angle of 50 degrees to maximize the heating of water in the colder months.

Solar energy captured from these collectors feeds into an electric heat pump that draws its environmental heat from water taken directly from the Elbe using a heat exchanger built into the base of the concrete pontoon. This provides both the heating and cooling requirements for the water and air conditioning of the building, with excess energy able to be temporarily saved for later use. The building features heating and cooling ceilings that either heat the rooms in colder months or cool the room in warmer months.

Figure 4 Exterior (left) and Interior (right) of IBA Dock
(Source: left photo by the author, 2011, right photo from
http://www.archdaily.com/288198/iba-dock-architech/, 2014)

The 44 kW heat pumps, along with a ventilating machine that provides air exchange for the entire building, are powered by 103 square meters of south-facing solar photovoltaic cells located on the roof terrace and angled at 30 degrees that deliver 14.8 kWp (kilowatt peak). The electricity needed by the heat pump is covered by the photovoltaic device on the IBA Dock. No further cooling or heating energy is needed (Darren Quick, 2012).

Floating hotel "Salt & Sill", Sweden (2008)

The first floating hotel in Sweden opened alongside the famous seafood restaurant "Salt & Sill". The location is small but peaceful island and very limited space was available around the restaurant. Therfore a floating hotel was the only way to realize the owners' dream to offer a complete service with food, drink, conference and accommodation at the same time (SALT & SILL, 2014). The hotel is very popular even though it is located in rural and coastal area in Sweden. So there are many visitors with different purposes all the year over.

Figure 5 Exterior (left) and Roof (right) of Floating Hotel "Salt & Sill"
(Source: photos by the author, 2011)

The floating hotel has 2 storeys and 23 rooms with 46 beds. All the rooms have their own entrance and access to an outdoor seating area. The building is mainly made of wood on concrete pontoon. Premises services (electricity, water supply and sewage) are served through connection lines between the floating hotel and the service station of near land.

During the construction of the building, protection of environment has been the most important agenda. A positive impact on outdoor life, little or no effect on the island environment, no noise and pollution of air should be kept. The building used local raw materials such as the pine wood from Swedish forests, and only environmentally friendly paint. They have even used the left over quarrying stone to build a new lobster reef under the concrete pontoon for the consideration of environment. In the hotel, heating energy is actually generated from the warm sea water underneath the floating building in winter (Costas Voyatzis, 2008).

Autark Home, Netherlands (2012)

Autark Home is a self-sufficient and passive floating home with European passive house certificate. A prototype of Autark Home is currently anchored in the river Maas, Maastricht, Netherlands and draws a huge number of eco-concious visitors due to its unconventional construction design.

The floating home has 2 storeys and 109.4 square meters floor area, outer wall with 55cm thick massive EPS, isolated windows and doors, triple glass and no cold bridges. In terms of energy, there is an ioloated water tank with capacity of 4,000 liters and 6 solar heat panels on the roof to keep the water at a temperature of 70 to 80 degree Celsius for 4 to 5 days (Autark Home, 2014).

Figure 6 Exterior (left) and Interior (right) of Autark Home
(Source: http://www.autarkhome.de/, 2014)

River water is converted to gray water and high-quality drinking water through a filter. And drinking water is made again by purification system through reverse osmosis in combination with the sand and UV filter. Gray water can be used as flushing & washing water and for the floor heating & cooling. Before the waste water returns to the river, the water is cleaned for 90% by a built-in filtration system. Like other passive houses, each room has its own ventilation. The incoming fresh air is heated or cooled by outgoing exhausted air through a heat recovery ventilation system.

The electricity is supplied by 24 solar photovoltaic cells with a total output of 6,360 Wp(watt peak). The electrical energy is stored in 24 batteries, each with a capacity of 1000 Ah, supplying enough electricity for 4 days for a normal family. The system can deliver 5300 kWh a year. On the display of the monitoring system in the living room, solar production can be viewed. In adverse weather conditions, a bio-diesel generator supplies the home with additional power (REM, 2012).

Even though there are no service utilities to be connected around the floating building, this kind of floating building with self-sufficient system can be built and operated without any problem. So floating architecture with self-sufficient system such as water treatment and electiricity power system can be built freely any distance away from the quayside.

RENEWABLE ENERGY APPLICATIONS IN SAMPLE FLOATING ARCHITECTURES

Renewable energy applications in sample floating architectures are as follows (see Table 1);

Table 1. Renewable Energy Application in Samples

Name of building	Renewable energy source	Remark
Floating Mosque	hydrothermal energy, solar PV cell	structure cooling system by water
The Ark	solar PV cell, solar heat panel , wind power	bioclimatic building, ETFE
IBA Dock	hydrothermal energy, solar heat panel, solar PV cell	prefabricated modular construction, heat exchanger
Floating hotel "Salt & Sill"	hydrothermal energy	environment protection
Autark Home	solar heat panel, solar PV cell	self-sufficient & passive system, bio-diesel generator, heat recovery ventilation system

Most popular renewable energy sources for the floating architectures are use of sloar energy (heat panel and PV cell) and hydrothermal energy. Especially use of hydrothermal energy may have a huge advantage in tropical region and polar region because there is a great temperature difference in the water and the outdoor air of the extreme climate regions.

Use of hydrothermal energy in renewable energy is applied to the projects such as Floating Mosque, IBA Dock, and floating hotel “Salt & Sill”. And solar PV cells are mostly used in the projects like Floating Mosque, The Ark, IBA Dock, and Autark Home. Solar heat panels are used for The Ark, IBA Dock and Autark Home.

Until now, it is very hard to find out wind power application in floating archietcture. Usually there is more wind resource on water space of sea or river than on urban land because there is daily land and sea breeze circulation and no windbreak on water. If small wind turbine with little noise is developed, it will be applied more often for the floating architecture on water than for the building on urban land.

Usually hybrid system of solar energy with wind power will be useful and complementary because the sun shines when there is no wind in day time and the wind usually rises when there is no sun. So solar - wind hybrid renewable energy system will be more popular when the design of the hybrid system is intergrated and harmonized with that of floating architecture.

CONCLUSION

Due to the climate change, people’s preference to live and enjoy activities on water, and frequent natural disasters like flooding & earthquake, floating architecture can be a strong and attractive alternative to the existing building on land. This paper aimed to investigate the renewable energy applications in floating architecture and to suggest some reference ideas for new building projects around waterside. Sample floating architectures with strong points of renewable energy application are chosen to analyze.

Comparing with the usual buildings on land, floating buildings on water have great advantages in terms of using renewable energy. Possibilities of solar energy and wind power are much higher in floating architecture because there are no obstacles around water space. And hydrothermal use of the water beneath the floating architecture is easier and more economic than geothermal use in the building on land.

Most popular renewable energy sources for the floating architecture are use of solar energy and hydrothermal energy. Especially use of hydrothermal energy may have a huge advantage in tropical region and polar region because there is a great temperature difference in the water and the outdoor air of the extreme climate regions.

It is very hard to find out the wind power applications in realized floating archietctures until nowadays. Usually there is more wind resources on water than on urban land because there is no windbreak on water space. And also there is daily land and sea breeze circulation around watersides. If small wind turbine with little noise is developed and integrated with the floating building design, wind power can have the priority to be applied due to product efficiency.

Hybrid renewable energy system of solar energy with wind power will be more popular when the design of the hybrid system is intergrated and harmonized with that of floating architecture. And also tidal power and wave power can be considerable to apply if proper system for the floating building is developed.

By the way, disadvantages of floating architectures such as shadows to the bottom, water pollution from concrete pontoon, and other negative effects to the ecosystem should be investigated in detail and countermeasures to overcome are to be suggested for further study.

ACKNOWLEDGMENTS

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Luminescent, Transparent and Colored, Pv Systems in Architecture: Potential Diffusion and Integration in the Built Environment

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ABSTRACT

The Luminescent Solar Concentrators (LSC) are transparent plates which contain dispersed fluorescent dyes that absorb a part of the solar light and emit it into the inside of the plate. By means of the total internal reflection, the emitted radiation is led towards the thin edges of the plate where it is concentrated on small surfaced conventional solar cells. The LSC seems a promising technology with large diffusion potentialities in architecture thanks to the transparency combined with energy production. In fact LSC technology could be positively integrated in transparent components (e.g.. shading devices, bow windows, greenhouses, glazed courtyards). The first experimental application of LSC technology at real scale is a bicycles shelter in Rome. The architectural and structural project has been designed in order to assess the LSC components performance in three different orientations (tilted east and west facing and a vertical west facing) and in combination with a shading system which improves the PV production.

INTRODUCTION

The LSC are transparent plates (plastic or glass) which contain dispersed fluorescent dyes that absorb a part of the solar light and emit it into the inside of the plate. By means of the total internal reflection, the emitted radiation is led towards the thin edges of the plate where it is concentrated on small surfaced conventional solar cells. This technology enables designers with a new tool to generate electricity while providing natural light inside the building thanks to its transparency. The LSC technology offers significant potential advantages over conventional silicon panels and solar concentrators based on mirrors or lenses. The plates can in fact collect both the direct and diffuse solar radiation, being efficient even under cloudy skies, and their installation is not subject to orientation problems. LSC plates are also made of cheap materials and significantly reduce the silicon surface needed to generate the same energy power. Even if the performance of LSC technology is not comparable to that of traditional photovoltaic, its complete transparency allows to make all glass surfaces energy producers. In particular this aspect is related to the desire of lightness and visual permeability of contemporary architecture. In addition, the presence of colour allows to characterize the building envelope.

The research carried out by Polytechnic University of Milan for Eni S.p.A., has the objective to study the development of building components based on LSC technology. The research focuses on the possible diffusion and integration of LSC technology in the built environment, analyzing mainly two aspects: the production of electrical energy and the interior lighting conditions.

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POTENTIAL DIFFUSION IN THE BUILT ENVIRONMENT

LSC panels can be used in a lot of different ways both in new buildings and in retrofit. On a morphological level the application of these components depends on their shape and their position relative to the building. The terms, purely evocative, that have been identified to indicate the different “scenarios of use” are: “between” (connection spaces between buildings, vertical connections, stairs and elevators, atria, light chimneys); “front” (curtain wall, fixed or opening windows, bow-window, double skin envelope, vertical or horizontal shading devices); “top” (volumes added as coverage as skylights, sheds, top of light chimneys, and technological spaces); “outdoor” (where LSC are used to build installations in open spaces such as urban equipment in parks and streets, temporary buildings, road barriers, etc.).

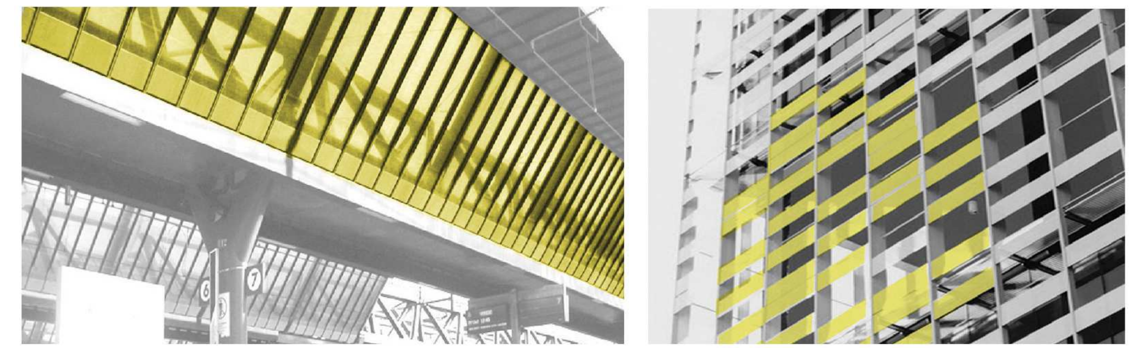

Figure 1 Examples of application of LSC in infrastructures and as shields on building facades (i.e. from left to right: A. Mangiarotti, studio 5+1AA, Jean Baptiste Pietri).

The colour of the LSC can be considered a problem but also a potential element to introduce colours pattern in the built environment and to modify the colour temperature in the interiors especially in offices where the dominant white finishing and artificial light with cold temperature require a warmer contribution. In fact, the application possibilities of LSC become even more interesting if measured at the sensorial level considering also the possible combinations with other materials: it is possible to emphasize the plate transparency or couple it with translucent materials to obtain a component that reduces visual permeability but lets the light pass through and therefore it is able to emphasize the value and charm of diffuse light. Different chromatic effects can be obtained: monochromatic ones using only panel of the same colour alternating with clear glass, or polychromatic ones combining the available colours of LSC (yellow, orange, red). Moreover modulating the size and the number of LSC panels and combining them with other materials (e.g. metal, glass, wood), different aesthetic effects can be achieved.

Also in this case the terms, purely evocative, that have been identified to indicate the different “sensorial scenarios” are: “transparency” (the plate is used as an element that guarantee the inside/outside visual contact and chromatically characterizes the architectural envelope); “translucency” (it is the scenario where LSC layers are coupled with a translucent element -e.g. satin glass- to have a component through which view is not possible but light can pass); “protection” (it regards the use of LSC elements as shading devices with the aim to modify the color quality of light and the perceptoin of colors in the room) and “opacity” (it is the scenario where LSC and an opaque layer are couped to increase the color intensity; this option does not permit the lighting, but increases energy efficiency).

Figure 2 Two possible visual effects of LSC: coloured transparency (G. Le Penhuel Architectes, Collège A. Schweitzer, Creteil, photo by J. Callejas), coloured translucency (DAPStudio E. Sacco-P. Danelli + architect P. Giaconia, Centro culturale Gritti, Ranica, photo by A. Bello).

THE EXPERIMENTAL APPLICATION

The first application at real scale of Eni technology was a shelter for electric bicycles in Rome. This project allowed to verify the strengths and the limitations of LSC panels from the energy production viewpoint (the shelter is still under monitoring) and from the construction process integration viewpoint (planning, design and implementation). The shelter is the ideal tool to simultaneously test the panels in different positions since the PV modules can be positioned with different orientations. Three orientations have been selected: inclined facing east, incline facing west and vertical east-west. The bike shelter was also equipped with a shading system made of reflective slabs plates placed at proper distance from the LSC to verify the PV production due to the increased indirect radiation on the LSC plates. The concept chosen for the project, called "energy module", defines the shelter as a set of modular free-standing elements that can be placed in different configurations in urban contexts.

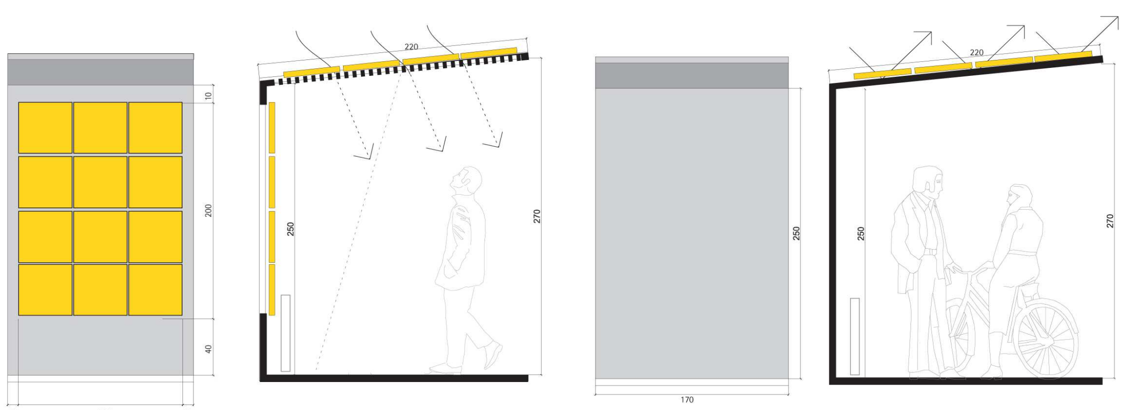

Figure 3 Two possible types of energy modules (from left to right): "shielded module" (with slats that filter light) and "full module" (with a reflective panel).

The modules can be combined, with more or less spacing between them, with different logics depending on the context in which they are placed. The frame module was developed in collaboration with Secco Sistemi S.p.A using only their standard products to minimize the process due to time constraints. The steel frame makes the module self-supporting and able to withstand the final assembly loads. The photovoltaic modules are made of 6 LSC panels each obtained with PMMA plates with dimensions of 50x50 cm assembled with properly dimensioned silicon solar cells connected in series/parallel. The panels are then connected in series to the stiffening structure made of painted steel, with dimensions of 108,4x161,8 cm. The panels are inserted into the frame and glued to ensure the resistance to atmospheric agents. Each module is equipped with 88 PV cells IXYS located on the 4 sides and connected in in parallel on each side; the four sides are connected in series and the panels that are connected in series using the structural steel elements in steel as ducts.

Figure 4 Twenty components made of 6 panels each have been used to build the shelter in Rome: 24 have been postioned on the roof and 8 in the vertical structure.

The selected steel profiles are glass retention systems bolted to steel box-shaped profiles for securing the LSC plates. A C-shaped aluminum frame is applied to the panel to protect the cells and bus. The profiles are equipped with butylic gaskets.

The peak power produced by every module is equal to14 Wp; the six modules are connected in series The electrical values evaluated in the flash test are listed in Table 1.

The average solar radiation per year on a horizontal unobstructed surface is expected to be 1307 kWh/m2 year. The average solar radiation per year on a unobstructed inclined surface (γ = 0°; ψ = 30°) is expected to be 1443 kWh/m^2 year. Average radiation on the module.

During the first monitoring period the module has been inclined 10° (γ = 0°; ψ = 10°). The average value on this surface is expected to be 1381 kWh/m^2 year. The average concentration factor for the panel has bees extimated between 8 and 20% with lower values in the late afternoon.

Table 1. Performance features of the experimental module LSC

Caracteristical data of the LSC module	Units	Value
Tension VMMP	V	24.29
Electricity IMMP	A	0.58
Electricity ISC	A	0.63
Power PMMP	W	14.1
tension VOC	V	30.16

Table 2. Recorded values for the LSC prototype during a three days monitoring in June

Day	Month	Daily Radiation [Wh]	Average Power [W]	Energy produced [Wh]
27	June	5557	10,87	79,74
28		6278	8,70	87,00
29		6617	8,59	85,88

Electrical scheme

The plant in question is stand-alone, with island operation. All the electrical loads need to be fed with alternating current at 230V, therefore the facility is equipped with an inverter able to supply the 230V to the loads drawing the necessary energy from the batteries. In detail, the generator of this photovoltaic system, made of photovoltaic modules and their connections and mechanical supports, is composed of a total of 32 prototype modules with monocrystalline silicon cells, installed at 3 different orientations and inclinations, as shown in the following summary table.

The different PV modules are connected in series of two modules each, thus forming a total of 16 strings. These strings are then grouped into three different sections, each of which is characterized by a uniform application type and is constituted by the electrical connection in parallel of the strings that compose it. The entire system is then equipped with a monitoring system able of measuring the voltage and current produced by each string, in addition to the main environmental data.

The electical needs for the bike shelter are related to: monitoring system for data collecting (solar radiation, temperature of the modules and air temperature, voltage and electricity); Personal computer with 19” touchscreen IP65 to visualize the energy produced and a multimedia description of the project; Back LED lighting of the Eni logo; Local LED lighting (positioned in the frame structure); N°3 electrical bikes.

System monitoring and remote control

The photovoltaic plant in question is equipped with an acquisition and monitoring system able to measure the following parameters: current strength of each string, the tension of each string, operating temperature of 3 photovoltaic modules, ambient temperature, radiation on the 3 different orientation planes under which the modules were mounted. The criteria selected for the analysis are: comparison between the integrated production of the LSC modules and the one estimated for traditional PV panels, definition and selection of significant days and tracking of the power supplied under different irradiation conditions, keeping the data coming from different panels orientations separate (bicycles side, motorcycle side, vertical wall), distinction of the strings according to the presence or absence of a back reflective panel, analysis of the historical production of the best performing strings.

The Eni photovoltaic shelter can nominally produce about 500 watts of electricity generated by 192 yellow transparent photovoltaic slabs, each of which is made of a plastic material with a minimum amount of dyes patented by Eni.

FUTURE DEVELOPMENTS

From the point of view of the type of component for the realization of the PV module, the initial choice fell on a frame with steel profiles with standard press-bents. The selected frame therefore guaranteed the same durability and mechanical strength of a traditional window frame with also the possibility to be easily opened for slabs repositioning. The next step is focused on a new fiberglass component structure which guarantees lightness, higher thermal and electrical insulation and minimum interference with the LSC energy performance in terms of minimum shading effect on solar cells.

Furthermore we are investigating the possibility of producing new components based on LSC technology. Nine concepts for different building components based on LSC technology have been defined. These components have been chosen for the potential diffusion in the built environment as well as for the possibility to be integrated in current building technologies. The dimentions of the LSC plates is based on a 50x50 cm module made in PMMA that can be aggregated to arrive at the desired dimensions. Each component will be studied and analyzed with reference to the current building regulations paying particular attention to the elements of the structural frame.

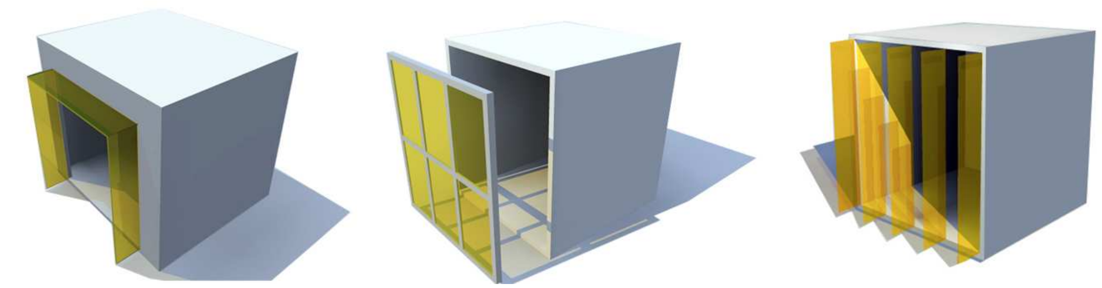

Figure 5 Some concept design for the future application developments.

CONCLUSION

The shelter, which is still in the monitoring phase, showed that the LSC are far less sensitive to the orientation than traditional photovoltaic panels; LSC are therefore able to exploit the diffused light and to work even in low lighting conditions (cloudy sky, sun low on the horizon).

This part of the research as well - as the building of the bike shelter - points out the necessity to create a new, strong expressive identity for the LSC, where color is directly related to the production of electrical energy. The appropriate use of color in the design of buildings and the relationship between colors and energy production will be a central theme in the continuation of the research.

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ANALYSIS OF DAYLIGHT PERFORMANCE IN CLASSROOMS IN HUMID AND HOT CLIMATE

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ABSTR ACT

This paper assesses the classrooms daylighting performance in hot and humid climate, by means of simulation in DAYSIM, considering the use of shadowed windows. The intention is to identify classrooms configurations that are still able to provide enough daylighting during the day. The study is orientated to the city of Natal, Northeast of Brazil, 5º S, on the coastal area, whose principles of passive building design emphasize daylighting and shading. An ambient with unshaded windows will be exposed to the excess of glare and thermal gains, inducing the occupants to close the curtains and turn the artificial lights on. Shading the window, it will be necessary to increase the window size to increase the diffuse light. Fortunately, these recommendations converge to create more opened architectural spaces, increasing the relation between inside and outside. However, the daylighting levels for different room depths depend on the combination of opening size and performance of the external shading. A classroom was modeled, simulated and analyzed, considering the combinations of three size openings (20 %, 40 % and 60% of window-to-wall ratio), four main façade orientations (North, South, East and West), and seven types of shading (horizontal overhang, drop edge overhang, 5º sloped overhang, horizontal overhang with side protection, horizontal overhang with three louvers, double horizontal overhang, double horizontal overhang with three louvers). Analyzes based on the useful daylight illuminance (UDI) showed limitations due to the occurrence of glare, caused by diffuse daylight next to the window. Detailed simulations confirmed a high level of influence of the combination of sky visible fraction and openings in the daylight performance.

Keywords: Daylighting, window-to-wall ratio, shading device.

INTRODUCTION

Despite the daylight availability in Brazilian cities, there are no recommendations for classrooms. This paper aims to discuss the daylight potentials in Natal. Natal, Northeast of Brazil, 5º of latitude, has great availability of diffuse light, but, according to the climate file, there is a lot of annual and daily variability in the daylight distribution. The diffuse light also causes glare, so it is important to design a shading device that also protects from this type of solar radiation. The hour of glare incidence depends on the orientation façade. The north and south façade receives solar radiation during almost the entire day, while the east façade has a better daylight distribution during the morning, and the west during the afternoon. This daily variation influences directly in the choice of the shading device. Façade orientations with fewer fluctuations can have a satisfactory daylight distribution with static shading devices, but façade orientations with more oscillations must have a dynamic shading device with manual or automatic control of the blinds and even of the lighting if it's necessary the integration between daylighting and electric light.

Mardaljevic and Nabil introduced (REINHART, MARDALJEVIC *et al.*, 2006, p.16) a dynamic daylight performance based on workplane illuminances, which determines when the daylight levels are 'useful' "for the occupant, that is neither too dark (100lux) nor too bright (2000lux). The upper threshold is meant to detect times when an oversupply of daylight might lead to visual and/thermal discomfort.”

Mardaljevic (MARDALJEVIC, *et al.*, 2011, p.5) on his study for daylight metrics in residential buildings suggests that “the occurrences of illuminances greater than 3,000lux (i.e UDI-e) should not, by design, be eliminated altogether, and that moderate occurrence may in fact be beneficial. What exactly the “optimum” levels of exposure might be is not yet known.

METHODOLOGY

The research method consists in a daylighting impact quantification of architectonical characteristics. The method consists of two approaches into two groups. There are variations in relation to the window-to-wall ratio (WWR), façade orientation and shading devices . From the behavior of the results of the first phase it was decided to make a refinement of the shading device geometry and the façade orientation. The procedures comprise the determination of hypothetical and representative models with different configurations, simulated in Daysim software (REINHART, 2010), which results are processed in spreadsheets developed specifically to complement the available metrics in Daysim, as shown in **Figure 1**.

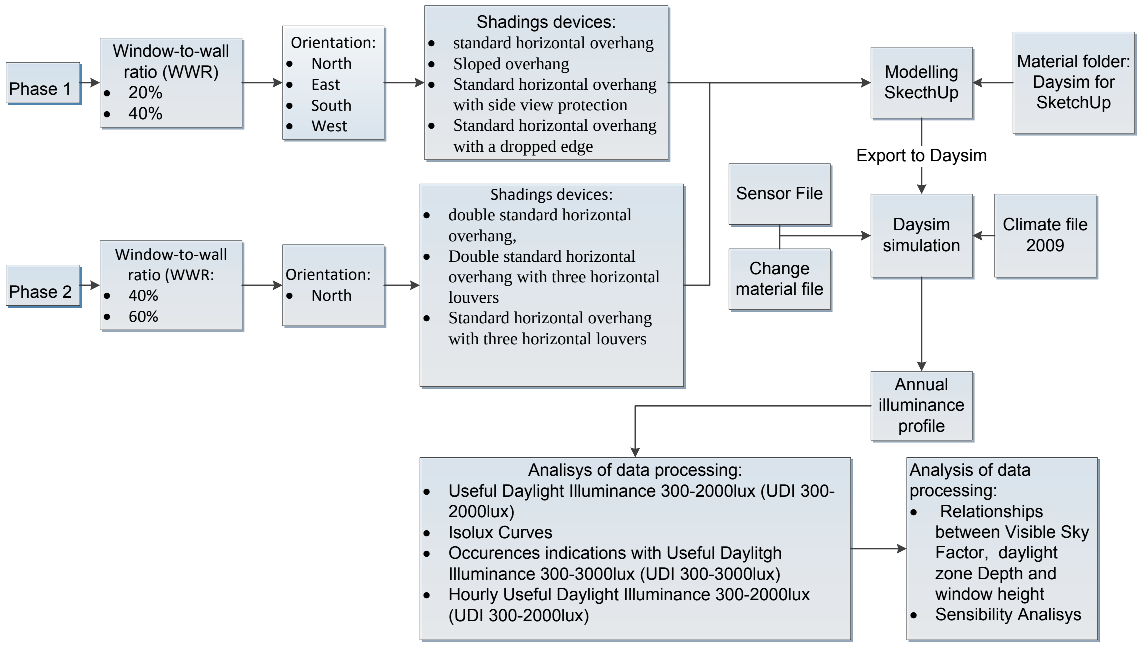


Figure 1 Research method steps.

The modelling concerns the input parameters of Daysim simulation software and presents the phases, procedures and sources detailed. The Daysim software was chosen due to the dynamic simulation, high processing speed, acceptable operationalization, outputs compatible for daylighting metrics processing and assessment.

Modelling

In the absence of a council law or guide for educational building, the model’s characteristics were obtained from the “Fundescola” legislation (FUNDESCOLA, 2002), which prescribes recommendations for schools projects. The cases analyzed are based on a common case, from which variations are created. The common features of all models are a classroom with dimensions of 7.20 m x 7.20 m. The simulations were realized with the empty room, without the distribution of the desks. The specularity properties used in this research were previously determined in the folder “Daysim for Sketch Up”, in the Daysim software.

1. Walls: 88% of reflectivity.
2. Ceiling: 88% of reflectivity.

3. Floor: 88% of reflectivity.
4. Openings: single pane glass with a visible transmittance of 90%.

The base case variations concern size of openings, façade orientation and shading devices, modelled in Sketch Up and exported to Daysim. There are three sizes of openings, characterized by Window-to-wall ration (WWR) of 20%, 40% and 60%.

Simulation

The Daysim simulation process consists of the input data, the simulation and the output data. The input data concerns climate file, modelling, sensor file, Daysim material database. The output data concerns daylight autonomy output file, daylight coefficient file, daylight factor output file, glare profile, annual illuminance profile, internal gains file for coupling with thermal simulations, and useful daylight illuminance. The annual illuminance file data was converted in percentages of useful daylight illuminance between 300-2000lux. The simulation process consisted of two phases:

1. Phase 1: classroom (7.20 m x 7.20 m), with window-to-wall-ratio (WWR) of 20 % and 40 % and shading devices, such as horizontal overhang, sloped overhang, horizontal overhang with side view protection, horizontal overhang with a drop edge, and light shelves in half or the models with WWR 40%, as shown in figures

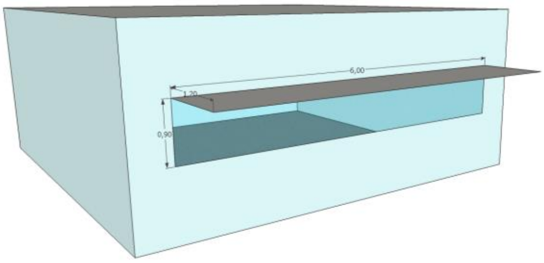


Figure 3 Horizontal overhang with WWR of 20%

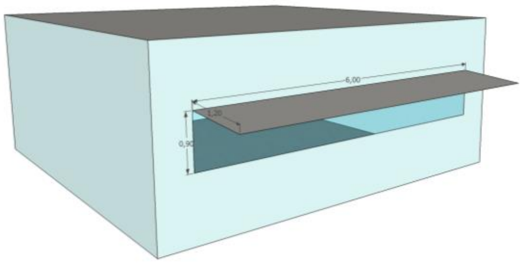


Figure 4 Sloped overhang with WWR of 20%

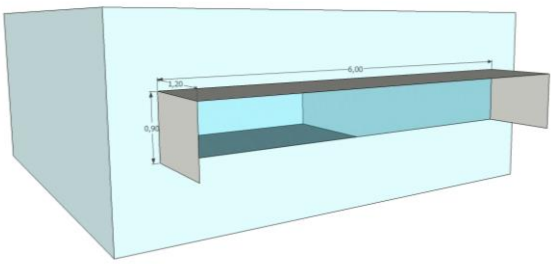


Figure 5 Horizontal overhang with side view protection with WWR of 20%

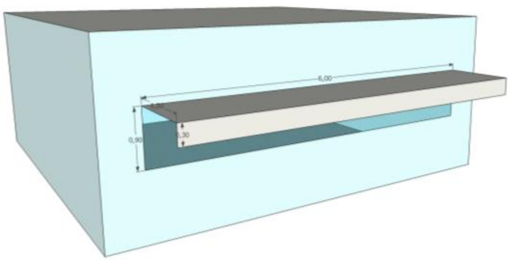


Figure 6 Horizontal overhang with drop edge with WWR of 20%

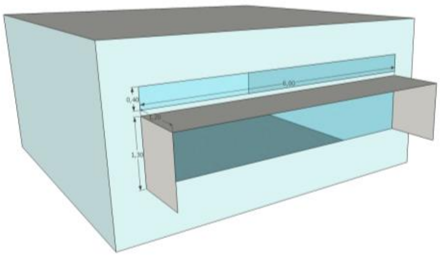


Figure 7 Horizontal overhang with WWR of 40%

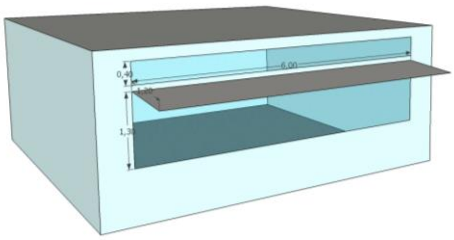
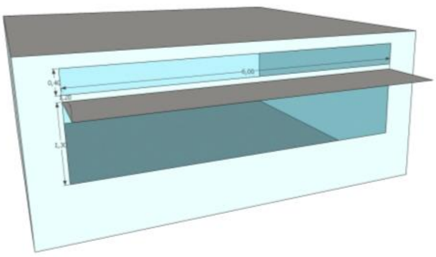


Figure 8 Sloped overhang with WWR of 40%



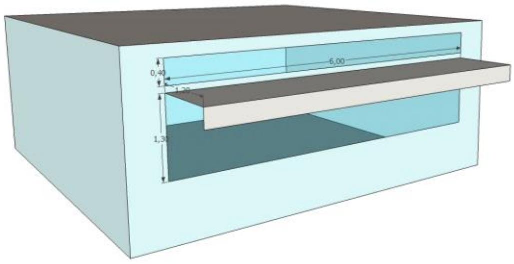
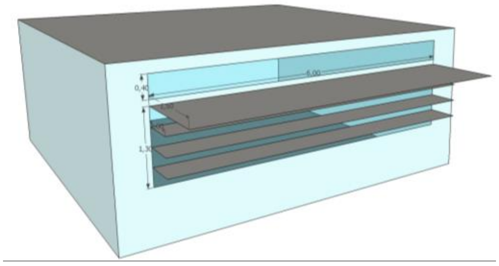


Figure 9 Horizontal overhang with side view protection with WWR of 40%

Figure 10 Horizontal overhang with drop edge with WWR of 40%

2. Phase 2: classroom (7.20 m x 7.20 m), with window-to-wall-ratio (WWR) of 40 % and 60 % and shading devices, such as double horizontal overhang, double horizontal overhang with three horizontal louvers, horizontal overhang with three horizontal louvers, besides the use of light shelves in half of the models;



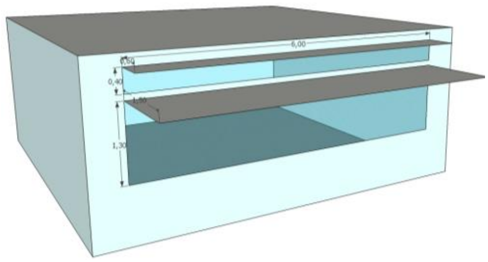
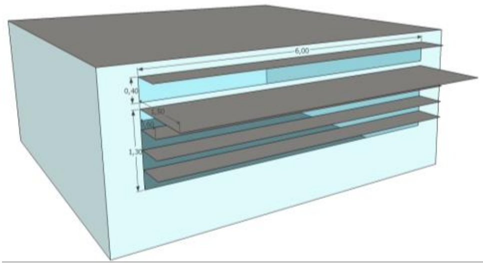


Figure 11 Double horizontal overhang with three louvers with WWR of 40%

Figure 12 Double horizontal overhang with WWR of 40%



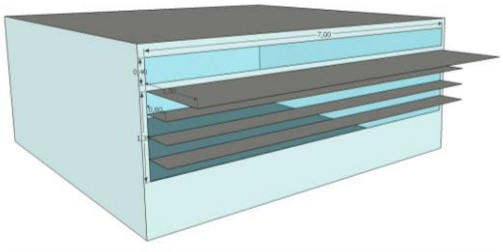
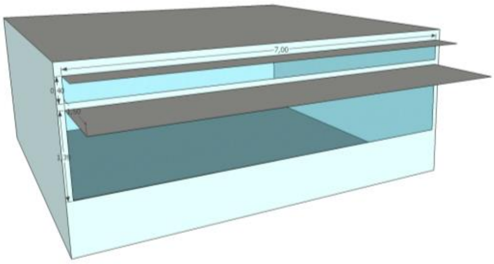


Figure 13 Double horizontal overhang with three louvers with WWR of 60%

Figure 14 Horizontal overhang with three louvers with WWR of 60%



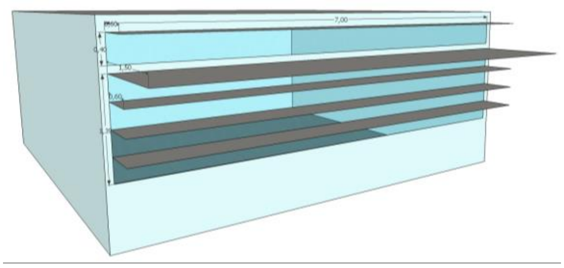


Figure 15 Double Horizontal overhang with WWR of 60%

Figure 16 Double Horizontal overhang with three louvers with WWR of 60%

The calculation of the sensor file is based on the standard NBR 15215-4 (ABNT, 2005, p. 6 e 7), which determines the number of the sensors through an equation that relates the width, depth, and height between the work plane and the topo of the window. The sensor file for WWR 20% had 36 sensor points and for WWR 40% and 60% had 16 sensor points.

Data processing

The data processing generated the following products: illuminance curves, useful daylight illuminance 300-2000lux (UDI 300-2000lux), isolux curves, hourly useful daylight illuminance 300-2000lux (UDI 300-2000lux) and occurrences indications with Useful Daylight Illuminance 300-3000lux (UDI 300-3000lux). The summer and winter solstices illuminance curves contribute to assess the daylighting distribution and the glare intensity, for each line of sensors, for each hour determined in the occupancy profile. The lower threshold of the Useful Daylight Illuminance was calculated according to the minimum illuminance level for classrooms prescribed in the Brazilian electric light regulation (ABNT, 2013, p.20), and the upper threshold was calculated for 2000lux according to Mardaljevic and Nabil (2005, apud REINHART, MARDALJEVIC *et al.*, 2006, p.16). The occurrences indication was calculated for a Useful Daylight Illuminace between 300-3000lux, according to the indication of Mardaljevic (2011, p.5). This last interval was calculated to test the improvement of daylight performance with the modification of the upper threshold.

The useful daylight illuminance was generated from the annual illuminance profile output, with illuminance data for each sensor points and each 1/12 per hour. The UDI 300-2000 lux spreadsheet was converted in isolux curves, as shown in **Figure 3**, generated in Surfer software by the Krigging method. LANDIM, MONTEIRO *et al* (2002, P.5) present a table summarizing the main interpolation methods. According to the authors, each method presents advantages and disadvantages, according to four categories: fidelity to the original data, smoothness of curves, computing speed, overall accuracy, as shown in **Table 3.** The Krigging method had the best accuracy and fidelity. The graphic represents the daylight distribution, easily understandable, as shows in **Table 2**.

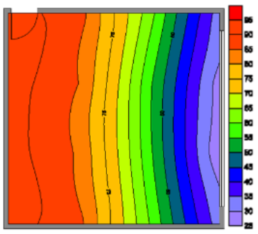


Figure 3 Isolux curves from east orientation, 40% WWR, horizontal overhang, with light shelf

Table 2 Interpolation methods (LANDIM, MONTEIRO *et al.*, 2002, p.4)

Algorithm	Fidelity to the original data	Smoothness of curves	Computing speed	Overall accuracy
Triangulation	1	5	1	5
Inverse distance	3	4	2	4
Surface Trend	5	1	3	3
Minimum curvature	4	2	4	2
Krigging	2	3	5	1

Scale	Qualification
1	Best performance
5	Worst performance

The hourly useful daylight illuminance 300-2000lux (UDI 300-2000lux), as shown in **Table 3 and Figure 4**, is an hourly occurrence for each day, based on the occupancy profile, from 08:00h to 16:00h. The occurrences indications with useful daylight illuminance between 300 and 3000lux, as shown in **Table 4**, indicates the percentage of glare, comfort and low illuminance for each zone. MARDALJEVIC et al. (2011, p.5) suggest that illuminances above 3000 lux should not be discarded, because the optimal daylight exposure level is still unknown, and the thermal gains can be mitigated by the use of an air-conditioner system.

Table 3 Hourly useful daylight illuminance 300-2000lux spreadsheet, north orientation, 60% WWR, double horizontal overhang with three horizontal louvers, without shelf

Horas / Sensor	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
07:00	93	78	56	45	89	82	59	48	92	81	56	45	93	77	60	44
08:00	95	98	94	91	97	98	94	91	98	98	94	90	98	97	95	90
09:00	86	99	98	97	95	99	98	97	95	99	98	97	95	99	98	97
10:00	81	98	98	98	91	98	98	98	91	98	98	98	90	98	99	98
11:00	84	95	96	96	90	95	95	96	88	95	96	96	85	95	96	97
12:00	93	98	98	99	94	97	98	99	92	98	98	99	82	98	98	99
13:00	98	99	99	98	99	99	99	98	97	99	98	98	89	99	99	98
14:00	99	98	97	96	99	98	97	96	91	98	97	96	96	98	97	96
15:00	98	95	91	89	97	95	91	89	87	95	91	88	97	94	91	87
16:00	89	81	69	59	87	82	68	58	88	80	63	52	88	76	65	45
17:00	37	40	41	42	38	39	41	43	38	40	42	42	38	40	41	42

Colour scale
0-10%
10-20%
20-30%
30-40%
40-50%
50-60%
60-70%
70-80%
80-90%
90% -99%
99%-100%

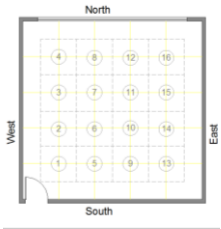
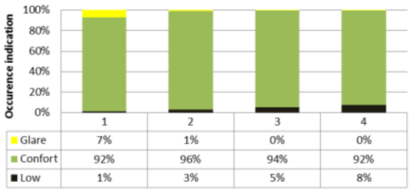


Figure 4 North orientation map of sensor

Table 4 Occurrences indications with useful daylight illuminance 300-3000lux, north orientation, 60% WWR, without light shelf



RESULTS AND DISCUSSION

Based on the illuminace curves, the light shelves perform better as internal shading. The light shelves didn't increase the daylight zone, or contribute to uniform the illuminance curve, but the glare incidence in the first row of sensors was reduced, in general, as shown in **Figure 5 and 6**, in the first graphic the highest illuminance curve was next to 3500lux, in the second case the highest illuminance level was 5000lux. The light shelf use reduces the glare incidence at the first row of sensors for almost a half.

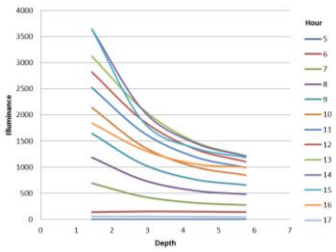


Figure 5 Illuminance curve for horizontal overhang, west orientation, 40%WWR, with light shelf

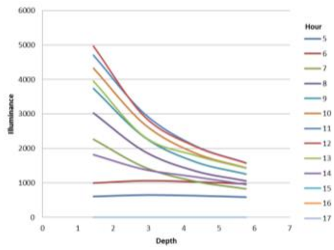


Figure 6 Illuminance curve for horizontal overhang, west orientation, 40%WWR, without light shelf

In general all of the 20% WWR models have an accentuated daylight curve close to the opening, and no glare occurrence, **Figure 6**, the daylight zone depth was smaller than the half of the room. The sloped overhang model had the best daylight distribution for east orientation, with 20% WWR. Other orientations produced UDI between 80% and 64% in the first row of sensors. The daylight zone depth was 1,95m, for a 90% UDI, for east orientation. The 40% WWR models simulated at the first phase have daylight zone depth equals de room depth, however with glare occurrence at the first row of sensors causes an UDI lower than 75%, as shown in Figure 7.

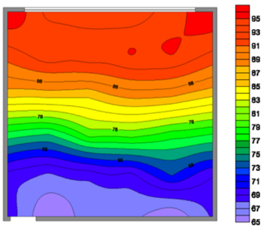


Figure 6 Isolux curves for sloped overhang, north orientation, 20% WWR, without light shelf

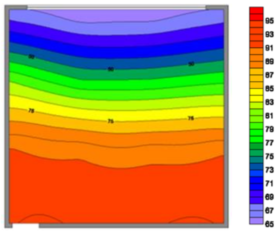


Figure 7 Isolux curves for sloped overhang, north orientation, WWR 40%, without light shelf

The first phase simulations demonstrates glare incidence in the first row of sensors, mainly for the 40% WWR (11h illuminance curve: highest illuminance value= 2000lux, lowest illuminance value= 750 lux), and high illuminance gradient for 20% WWR (11h illuminance curve: highest illuminance value= 1200, lowest illuminance value= 450lux), as shown in **Figures 8 and 9**, the daylight distribution varies during the day.

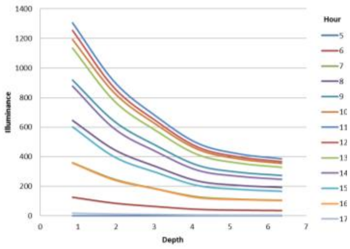


Figure 8 Illuminance curve for horizontal overhang with drop edge, WWR 20%, without light shelf, south orientation

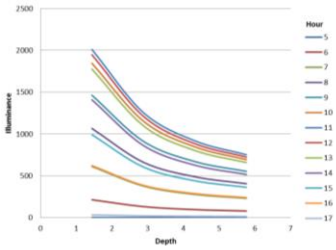


Figure 9 Illuminance curve for horizontal overhang with drop edge, WWR 40%, without light shelf, south orientation

The UDI table shows the values of UDI for the different sensors, according to the sensors map. It was detected a 90% UDI only for the period between 9:00h and 14:00h for east orientation model, as shown in **Table 5 and Figure 10.**

Table 5 Hourly useful daylight illuminance 300-2000lux spreadsheet, east orientation, 20% WWR, horizontal overhang, without shelf

Horas / Sensor	31	25	19	13	7	1	32	26	20	14	8	2	33	27	21	15	9	3	34	28	22	16	10	4	35	29	23	17	11	5	36	30	24	18	12	6
07:00	83	79	61	39	30	26	82	83	65	42	31	28	83	85	67	44	31	28	81	85	68	47	32	29	84	83	65	44	32	26	83	78	58	40	30	24
08:00	85	97	94	82	71	62	78	98	95	85	72	68	76	98	95	86	71	66	73	98	95	89	73	67	80	98	95	86	74	63	74	97	92	83	70	58
09:00	88	99	97	93	87	82	76	99	98	94	87	85	72	99	98	95	87	84	67	99	98	96	88	85	75	99	98	95	88	83	85	99	97	93	87	79
10:00	91	99	98	96	93	91	74	99	99	97	93	92	66	99	99	97	93	92	60	99	99	97	94	92	71	99	99	97	94	91	93	99	98	96	94	89
11:00	94	99	99	97	95	94	82	99	99	97	95	95	68	99	99	97	95	95	61	99	99	98	96	95	76	99	99	98	96	94	97	99	98	97	95	92
12:00	98	99	99	97	96	94	94	99	99	98	96	95	85	99	99	98	96	95	79	99	99	98	96	95	91	99	99	98	96	94	99	99	99	98	96	93
13:00	99	99	98	97	95	92	99	99	98	97	95	93	98	99	98	97	95	93	98	99	98	98	96	94	98	99	98	98	96	93	99	99	98	97	95	91
14:00	99	98	96	90	80	68	99	98	96	91	82	75	99	98	97	92	82	75	99	98	97	93	84	77	99	98	96	93	84	73	99	98	96	91	82	65
15:00	97	92	81	51	20	6	97	93	84	57	23	12	98	95	85	61	23	13	98	95	86	66	29	15	97	94	84	64	29	11	97	92	80	57	23	5
16:00	82	60	35	11	6	4	86	67	40	13	6	6	87	75	44	13	6	5	88	75	45	17	7	6	86	69	40	15	8	5	82	62	31	13	7	3
17:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	0	3	5	6	7	5	3

Colour scale
0-10%
10-20%
20-30%
30-40%
40-50%
50-60%
60-70%
70-80%
80-90%
90% -99%
99%-100%

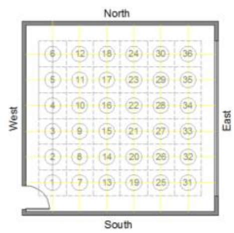


Figure 10 East orientation map of sensor

The second simulation phase was realized with 12 different models, only for the north orientation, with two openings size (the 40% and 60% WWR), three different shading devices (horizontal overhang with three louvers, double horizontal overhang, double horizontal overhang with three louvers) and with or without light shelves.

The double horizontal overhang had a similar effect to light shelf, reducing the glare incidence in the first row of sensors. The models' daylight distribution with no light shelves performed better with 40%WWR; the 60% WWR had a reduction of a glare incidence in first row of sensors. To decrease this incidence and improve the daylight distribution, it was inserted internal shading device in the light shelves. The 40%WWR model accentuated the illuminance gradient, reducing the daylight zone depth, as shown in **Figure 11 and 12.** The 60% WWR model resulted in a better daylight distribution and low glare occurrence, as shown in **Figure 13 and 14.**

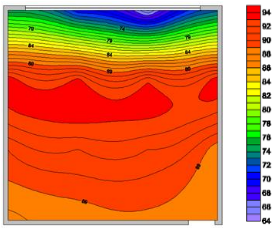


Figure 11 Double overhang with three louvers, WWR 40%, north, without shelf

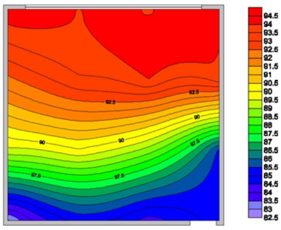


Figure 12 Double overhang with three louvers, WWR 40%, north, with light shelf

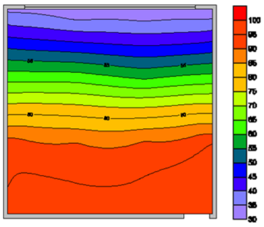


Figure 13 Double overhang, WWR 60%, north, without shelf

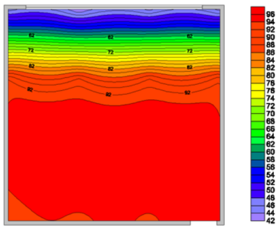
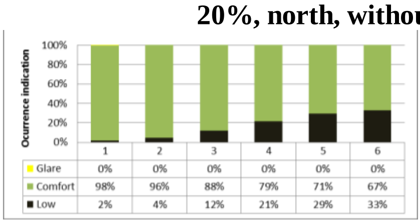


Figure 14 Double overhang, WWR 60%, north, without light shelf

The occurrence indication detects the glare occurrences in a UDI between 300-3000lux for each daylight zone. The daylight zone distribution was done according to the sensor map, which has some variations according to the façade orientation. Each table bar refers to one daylight zone at the sensor map, according to the figures 15, 16, and 17. The change of the UDI upper threshold to 3000lux had increased the occupants' comfort level frequency, mainly in 40% WWR models. The 20% WWR model with the best performance was the horizontal overhang with the best comfort indication in the daylight zone six (67%), comparing to the other models that had lowest indications (sloped overhang - 61%, horizontal overhang with side protection – 59%, horizontal overhang with drop edge – 49%), as shown in **Table 6.** The 40% WWR opening with the best daylight distribution was the double horizontal overhang with three louvers with light shelf had a first row of sensors with a glare indication of 0%, as shown in **Table 7**. The 60% WWR opening with the best daylight distribution was the double horizontal overhang with three louvers and light shelf had the first row of sensors with glare indication of 1%, as shown in **Table 8**. In the second phase models the glare occurrence was reduced or eliminated in both size of openings (40% and 60% WWR), but for the 40% WWR there was a bigger reduction in the daylight zone six than in the 60% WWR (81% - in the first, 87% in the second).

Table 6 Horizontal overhang, WWR 20%, north, without shelf



	1	2	3	4	5	6
Glare	0%	0%	0%	0%	0%	0%
Comfort	98%	96%	88%	79%	71%	67%
Low	2%	4%	12%	21%	29%	33%

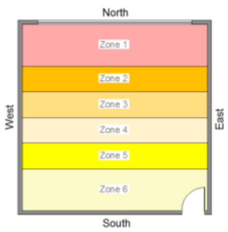
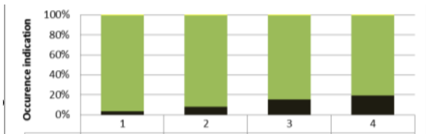


Figure 15 Daylight zones for the WWR of 20% fort the North façade

Table 7 Double horizontal overhang with three louvers with light shelf 40% WWR



	1	2	3	4
Glare	0%	0%	0%	0%
Comfort	96%	92%	85%	81%
Low	3%	8%	15%	19%

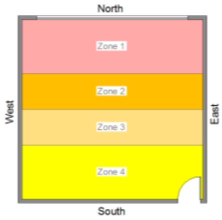
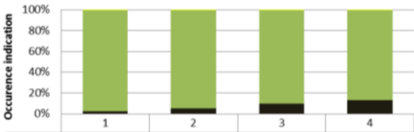


Figure 16 Daylight zones for the WWR of 40% fort the North façade

Table 8 Double horizontal overhang with three louvers and with light shelf 60% WWR



	1	2	3	4
Glare	1%	0%	0%	0%
Confort	97%	95%	90%	87%
Low	2%	5%	10%	13%

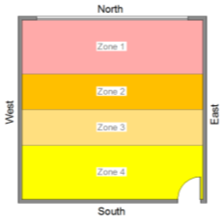


Figure 17 Daylight zones for the WWR of 60% fort the North façade

CONCLUSION

The analysis method demonstrated that a single criterion is not enough, leading to combine other resources, such as illuminance curves for each time of the day, for each month of the year of the climate file, calculation of UDI between 300 and 2000lux to obtain a flexible and suitable interval, visible sky factor quantification for each opening and shading system, introduction of occurrences indications with UDI between 300 and 3000lux

The performance comparison among different fenestration systems and orientations indicates few differences, with UDI varying between 90% to 100 %, while the annual and daily daylight variability are very significant. The shelves were used as an internal shading system, avoiding the glare in the first row of sensors, and reducing the daylight zone. This system was suitable to 60%WWR and the glare eliminated at the first row of sensors while 40% WWR has reduced 50% of the daylight zone.

Each WWR had different daylight performances: In the phase 1 the 20% WWR didn’t have glare occurrences, but the daylight curve had a high declination after the daylight zone of 3,50m. In the phase 1 the 40% WWR had glare occurrences in the first row of sensors, which was reduced with the use of louvers. In the phase 2 the 40% and the 60% WWR had the glare occurrences reduced or eliminated in the first row of sensors. The daylight zone of 40% WWR had a variation between 3,54m and 4,75m and the daylight zone of 60% WWR had achieved a daylight zone of 7,20m.

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Session PG : Passive Design

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Contentment - Knowledge Consortium of Gujarat

Energy codes for Mediterranean Climates: comparing the energy efficiency of High and Low Mass residential buildings in California and Cyprus.

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ABSTRACT

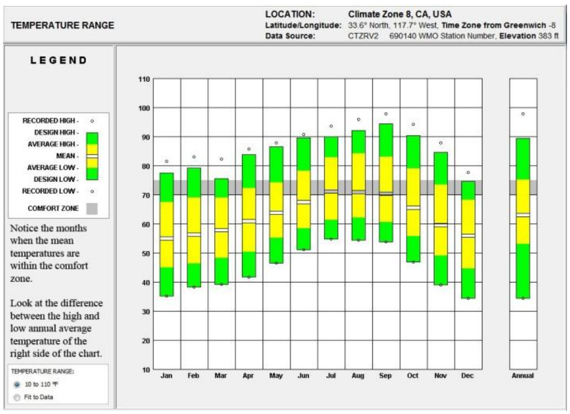
Population growth, city sprawls, increase of households and overuse of resources, affect the environment and impact greatly the energy use. About 40% of the energy demand in US and Europe goes to the buildings, with residential exceeding the commercial. Building codes and energy standards aim to reduce the consumption by setting minimum standards. "Architecture 2030" and "Europe 2020" target a higher reduction. Energy simulations are the first step towards the goals. Energy code compliance software evaluate energy and environmental performance of a building by approving or rejecting it according to the estimated outcome. Variations of materials, building strategies and systems affect the energy use and consequently its efficiency. How do two different compliance code software programs, evaluate a same building performance in a Mediterranean climate? For this study, a comparative analysis using two code compliance software: Energy Pro and iSBEM-CY has been conducted. A two story simple family detached house was selected with two construction design options: (a) high thermal mass and (b) low thermal mass in the sub-tropical Mediterranean climate. For this selected climate condition, Los Angeles in California and, and Larnaca in Cyprus were chosen in the study. Through this comparison the variations have been examined whether they meet both codes and ultimately the most energy efficient design option for each region has been identified. Differences in the inputs, outputs and parameters between the two software programs which are estimated to have impacted the results have been identified and described.

INTRODUCTION

Building energy usage accounts for 40% of the total energy consumption in the U.S. (DOE, 2008). Architecture 2030 and Europe 2020 target the reduction of the building energy sector by 50% to 100% (i.e., net zero energy). Federal and State energy codes and requirements become more stringent to meet the energy reduction target. Although the number of households increased in the U.S. from 1980-2009, the average household energy consumption actually decreased (RECS, 2013). In contrast, household energy consumption in the EU-27 increased by 7.5% (EEA, 2012) between 1990 and 2009.

Energy consumption in buildings has a major impact not only on the environment but also on building occupants' environmental comfort. Since 90% of the modern people spend their time indoors (EPA, Report to Congress on indoor air quality: Volume 2. EPA/400/1-89/001C, 1989), thermal comfort and indoor environmental quality have a great impact on people's health and productivity. Therefore, the design of a building should consider the climate conditions. The Mediterranean climate in both cities studied, Los Angeles **as shown in Figure 1** and Larnaca **as shown in Figure 2**, is sub-tropical, with the warm to hot summer and mild winter. Both climates are semi-arid.

Climate change, urban sprawl, and heat island effect have increased building energy demands. Depending on the heating and cooling seasons, temperature swings between indoor and outdoor environment vary. More specifically, and from a climatic perspective, the parameters that affect this fluctuation are humidity, solar radiation, outdoor temperature, etc. For indoor conditions, the number of occupants, their activities, lighting, and equipment all contribute to the energy consumption. High peak loads, especially during the summer, can result in the use of bigger mechanical systems. Consequently, the amount of energy use increases and operating costs follow accordingly. A major building component which affects buildings energy usage and its efficiency is its envelope. Therefore it is necessary to study the climate conditions of every site location and to identify the most appropriate design strategies for it.



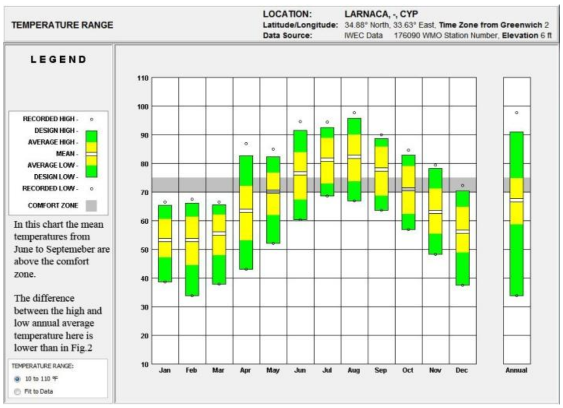


Figure 1 Annual temperature range (°F) for California climate zone 8 from Climate Consultant.

Figure 2 Annual temperature range (°F) for Larnaca, Cyprus from Climate Consultant.

The annual average and monthly temperature ranges of the two locations **are shown in Figures 1** and **Figure 2**. Mean temperatures in Los Angeles (Figure 2), located in California climate zone 8 are within the comfort zone in July, August, and September. The rest are below the comfort zone and heating is required. The average annual ΔT in Los Angeles is 21°F (6.1 C°) with the highest recorded temperature at 98°F (36.6 C°) and the lowest at 34°F (1.1C°). In Cyprus, only May and October provide mean temperatures within the comfort zone. From June to September there is a need for cooling. The rest of the months show a heating demand. The average annual ΔT in Larnaca is 7°F (13.8 C°) with the highest recorded temperature at 98°F (36.6 C°) and the lowest at 34°F (1.1 C°).

HIGH & LOW MASS BUILDING PERFORMANCE IN MEDITERRANEAN CLIMATES

Historically, buildings in Mediterranean climates were constructed with high mass materials. Specifically in Cyprus, for the vernacular architecture, stone and adobe blocks were mainly used in the structure. Nowadays, the majority of the residential buildings are constructed with concrete and brick. Controversially, in California’s dwelling history, buildings tended to be of lightweight construction, primarily wood. Until today, the tradition of lightweight buildings is still the common practice for residences. Materials with high thermal capacity absorb solar radiation during the day and release it during the night. This property of the materials has been used in architecture as a passive strategy to achieve desired indoor temperature levels and comfort. By contrast, materials with low thermal capacity have a limitation in storing heat. As a result, this thermal phenomenon can cause the shift of peak temperatures between indoors and outdoors very quickly, i.e. thermal lag is reduced. This study examined the properties and performance of the typical high and low mass envelopes in a residential building for the Mediterranean climate of Los Angeles and Larnaca. Thermal mass is classified into (a) exterior thermal mass- defined as the mass of the elements which are exposed to the exterior environment, and (b) interior thermal mass- defined as the mass of the elements inside the envelope such as interior walls, floors, chimneys, ceilings, etc. (Chi-wai, 2003). In this study, thermal mass refers to the constructed building elements, both interior and exterior, excluding any movable objects such as furniture.

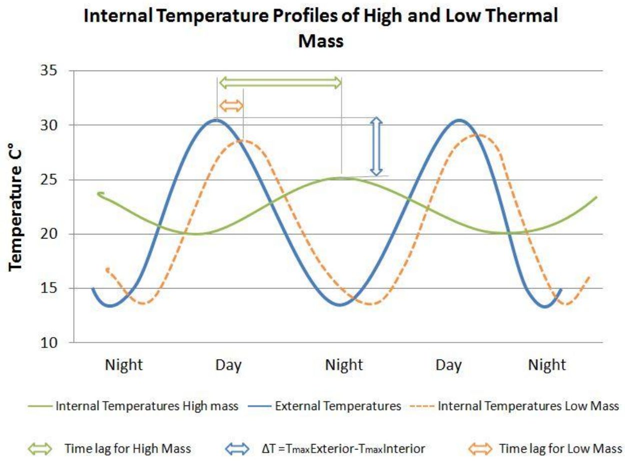


Figure 3 Internal temperature profiles of high and low levels of thermal mass.

High Mass - Cyprus

Residential buildings in Cyprus are primarily constructed out of high mass materials. The building structure is made out of reinforced concrete and the non-bearing walls with brick. There are two main variations for the wall assemblies in the iSBEM-CY code compliance software:

1. Double brick wall 1'(30cm) thickness with 2"(5cm) air gap in the middle, U-value 0.198Btu/ $ft^{2°}F$ (SI: 1.29W/ m^2K).
2. Double brick wall 1'(30cm) thickness with 1"(2.5cm) air gap and 1"(2.5cm) extruded polystyrene U-value 0.107Btu/ $ft^{2°}F$ (SI: 0.608 W/ m^2K).

According to the Cypriot building code only the second material assembly (b), complies with the energy rating standards. A wall with higher U-value than 0.149 Btu/ $ft^{2°}F$, even if it has such a relatively low insulation-performance, is allowed when the thermal mass is adopted as a passive strategy for heating and cooling. These wall assemblies are both provided in the Cypriot code compliance software.

Low Mass – California

For a California residential building, the wall assembly was preselected from HEED, Scheme 1: the auto generated code compliance energy model was adopted:

1. Stucco or Face brick on 2x4 Wood studs at 16" with Plaster board interior with the U-value 0.09 Btu/ ft2°F (SI: 0.511 W/ m^2K).

METHODS & APPROACH

For this study, a single family detached house of 1,600 sq.ft. (148.64m^2) was initially designed in HEED (Home Energy Efficient Design). HEED is an energy design tool primarily used for low rise residential buildings. For the performance comparisons, two building energy models were used in each location, Los Angeles and Larnaca: high and low mass .During the study it was observed that in HEED the Larnaca climate was translated into California climate zone 8. The energy performance of the high mass simulation showed an annual average EUI of 28.07 kbtu/sf/y (88.55 Kwh/m^2), and an EUI of 34.81 kbtu/sf/y (109.81 Kwh/m^2) was estimated for the low mass. From this comparison the first drawn conclusion is that the high mass buildings are more efficient overall throughout the year than the low mass for the Mediterranean climate. The next step was to use EnergyPro to identify whether the models comply with the California energy code, Title 24. Similarly, the models were designed to the corresponding Cypriot code compliance software iSBEM-CY. The generated outcomes from the two code compliance software were compared. Software similarities and differences were found and described.

EnergyPro

EnergyPro is one of the California code compliance (Title 24) energy analysis program and one of its potential is the energy verification for low-rise residential buildings and whether they comply with the energy code. For the purpose of issuing a certificate based on the code, the software is originally designed only for California climates, and the software adopts DOE-2 for a simulation engine. The Larnaca climate files were not able to be used per the software notification: Larnaca does not have a valid California Climate Zone for the California Title 24 calculations. In order to run the models the Los Angeles weather file Climate 8 was used. All the building elements were checked and verified in the software. The models were designed as single zone for more accurate calculations of the thermal mass impact to their energy use intensity.

High and Low mass building in EnergyPro. EnergyPro assumes certain thermal mass characteristics for the calculations. All residential buildings are considered to contain a pre-set amount of “light” thermal mass. Heavy thermal mass is modeled based on the conditioned area of slab floor as 20% exposed 80% of it as rug-covered slab and 5% of the non-slab area as exposed 2 inch thick concrete (EnergySoft, 2011). Concrete floors that are covered by carpet are not considered exposed thermal mass.

For the calculations of the high mass building loads, all the required values were taken from the Cypriot code and converted to IP units. The material properties selected in this study are listed in Tables 1 and 2. Walls, roof and floor had to be customized in order to generate the same U- values. The U-values were managed to be adjusted 95%. One of the of the software’s limitation is that customizing high mass components for Heat Capacity (HC) is not possible. A default HC condition of the selected wall type was adopted in this study, while some of the other elements were changed to “0” as shown in Table 2.

Performance of the thermal mass in EnergyPro. Using Energy Pro, an experiment was made before the residential building was modeled. The scope was to identify whether the software encountered the thermal mass impact to the energy use intensity by changing the settings of the thermal mass for roof, walls and floor. In the software two available options exist regarding the thermal mass and how it affects the energy calculations, these are: None or Mass Type. Under Mass type these variations are available: Adobe, Concrete heavyweight, Concrete lightweight, Masonry partial grout, Masonry solid grout, Wood solid logs and Wood cavity wall. After selecting the Mass type the option of having it exposed (as pre-mentioned above) or not is available. Furthermore, the thickness of the mass can be imputed.

For the testing, a Masonry partial grout wall was used, and the heavyweight concrete mass was selected for the roof and floor. Two variations were made. **Figure 4** shows the performance of the same envelope “with non exposed mass” and “with exposed mass”. The form of the line demonstrates the effect of the thermal mass to the envelope’s efficiency. The smooth curve illustrates this transition and decrease of the EUI as expected. During the experiment, none of the other settings in the model were changed. The total ΔEUI between the 6” (0.15m) non-exposed to 30” (0.76m) thickness exposed is about 6kBTU/sq.ft./y (18.92 Kwh/m^2).

The next step was to examine the effect of the thermal mass to the overall building’s performance. In this case all the building systems were used as per the code requirements. The efficiency of the systems is listed in Table 1. Similarly, two runs were made, with the mass non-exposed and exposed. **As shown in Figure 5**, it is clear that the exposed thermal mass contributes to the reduction of the energy loads and can be calculated in EnergyPro.

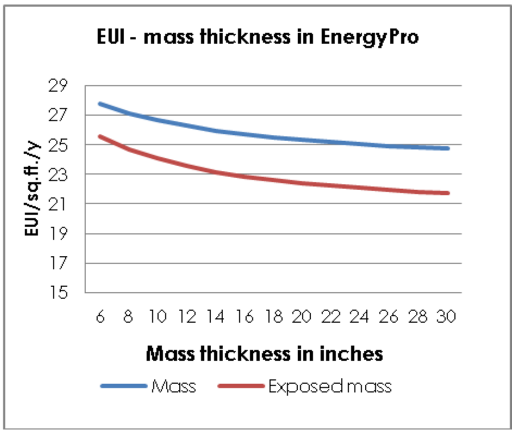


Figure 4 Relation of EUI and thickness.

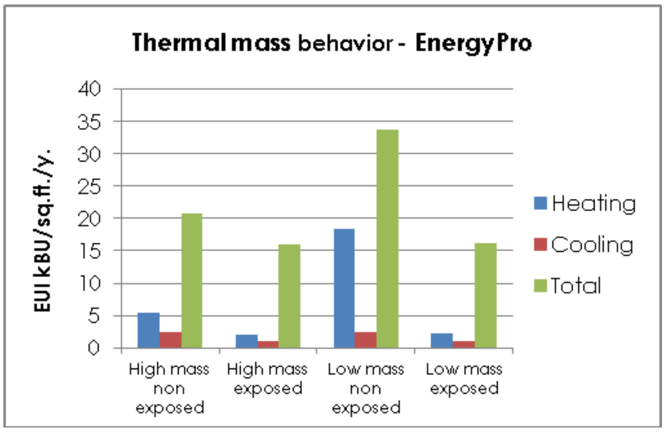


Figure 5 Thermal mass behavior in Energy Pro.

iSBEM-CY

For Cyprus, the corresponding code compliance software is iSBEM, which stands for interface of Simplified Building Energy Model. The program is based to the British SBEM software and BRE rating system. Since the law of certifying buildings' performance launched in 2010, the iSBEM-CY is new and consequently has some limitations. The rating system of certifying buildings has a range from A to F. A building will be certified only if meets at least the "B" rating score of EUI: "A" < 15.99 kBtu/ ft2, "B" from 16 kBtu/ft2 to 31.99 kBtu/ ft2, "C" from 32 kBtu/ ft2 to 46.99 kBtu/ ft2, "D" from 47 kBtu/ ft2 to 63.69 kBtu/ ft2, "E" from 63.7 kBtu/ ft2 to 94.99 kBtu/ ft2 and "F' > 95 kBtu/ ft2.

High mass building in iSBEM-CY. For the design of the model that meets the code, the building elements with the highest U-values were used. This was made for two reasons:

1. To test if the model will get a certification.First numbered item
2. To compare its energy use intensity with the model in EnergyPro Second numbered item

In iSBEM-CY as mentioned at 2.1 High mass – Cyprus, only two available wall assemblies exist: the one with higher U-value than the code requirement and one that meets the requirements. In the user's manual there was no reference for the one that does not apply. The assumption for the first type is that it's being used for existing buildings. If none of the above choices is desired, alternatively someone can input its own U-Value. Similarly, the "Cm" setting, which is the Heat Capacity of the element, can be modified. There is no option for changing the thickness as in EnergyPro. In the same way all the envelope elements such as roof, floors, doors and windows, can be adjusted. Regarding the effect of thermal mass in the iSBEM-CY, it is not clear yet. More details are given at 3.3 Comparison of performance and 3.4 Comparison of software.

Low mass building in iSBEM-CY. For the design of the low mass code compliance building from California, all the values and units were converted from IP to SI. The U-values and heat transfer coefficient were inputted. Therefore, walls, roofs, floors, doors, were only assigned by these properties while glazing had additionally the Tvis (L-solar) and SHGC (T-solar). Table 2 shows all the values and units required for the high and low mass code compliance residential buildings of Los Angeles and Larnaca.

COMPARISON OF PERFORMANCE

Overall four runs were made in the two software, EnergyPro and iSBEM-CY: In EnergyPro: High mass that meets the Cypriot code and, Low mass Title 24 code compliance. In iSBEM-CY: High mass that meets the Cypriot code and Low mass Title 24 code compliance. For the highest possible accurate results the same HVAC and domestic hot water (DHW) systems were used as shown in Table 1.

Table 1. Building Systems and Efficiency

System	Type	Efficiency
DHW	Gas Boiler	59% Energy Factor
Heating	Gas Furnace/Boiler	78% AFUE
Cooling	Split System	SEER 13, EER 13

In EnergyPro, model (2) was the low mass Title 24 code compliance. The goal was to see if a residential house which complies as “B” performance to the Cypriot code would comply to Title 24. Indeed, the runs showed that the model did meet the California code requirements.Similarly, model (4) was designed in iSBEM-CY, with the standards of the California code. In this case, the model met the requirements of the Cypriot code and was classified as “B” in its performance.Table2 shows the inputs used in the two software and the modifications that were made in order to abridge the models between their values as much as possible. In the Building components “h/m” stands for the propertied of the high mass energy model, and “l/m” for low mass.

Table 2. Building Component Properties

Building Compo nent	EnergyPro U-value Btu/h ft2°F	EnergyPro HC Btu/ ft²°F	iSBEM-CY U-value Btu/h ft2°F	iSBEM-CY HC Btu/h ft2°F
Wall (h/m)	0.148	16.3	0.149	5.145
Wall (l/m)	0.095	0	0.095	0.10
Roof (h/m)	0.131	0	0.132	11.025
Roof (l/ m)	0.028	0	0.028	0.10
Floor (h/ m)	0.36	0	0.35	11.368
Floor (l/m)	0.034	0	0.034	0.1
Door (h/ m)	0.60	0	0.669	0.49
Door (l/ m)	0.50	0	0.50	0.10
Glass (h/m)	0.67	Tsolar=SHGC=0.76 Lsolar=Tvis=0.80	0.669	Tsolar=SHGC=0.76 Lsolar=Tvis=0.80
Glass (l/m)	0.669	Tsolar=SHGC=0.76 Lsolar=Tvis=0.80	0.40	Tsolar=SHGC=0.40 Lsolar=Tvis=0.49

The energy use intensity of the models in the two software programs **is shown in Figure 6**. As illustrated, the high mass residential building in EnergyPro is more efficient that the low mass. In contrast, in the iSBEM-CY the low mass is shown to be more energy saving. The assumption for this difference lies in two possible reasons:

1. The iSBEM-CY does not calculate in the same way thermal mass as the EnergyPro High mass that meets the Cypriot code.
2. The lack of the elements thickness customization when changing the U-value and heat capacity of the assembly might not reflect the performance respectively.

The difference between the two software results in performance is beyond 100% in EUI **as shown in Figure 6.** The outocomes were expected vart but the disparity had not been anticipated to be so high. The results were estimated to differ due to the factors **shown in Table 3**. The software engines for the performance calculations differ. EnergyPlus has a higher resolution of inputs than iSBEM-CY, which is a simplified building energy modeling tool taking many parameters as defaults. Therefore the algorithms for heat transfer or the alculation of infiltration, radiation and conduction etc. are different; but they have not been examined for the research. The weather files used in the software differ and their values impact the performance calculations. Geometry in this study was the same. Finally the compatibility of the file format for comparison would provide more answers but iSBEM-CY does not use or generate .gbXML files or similar; and consequently more detailed comparison between the files could not be implemented.

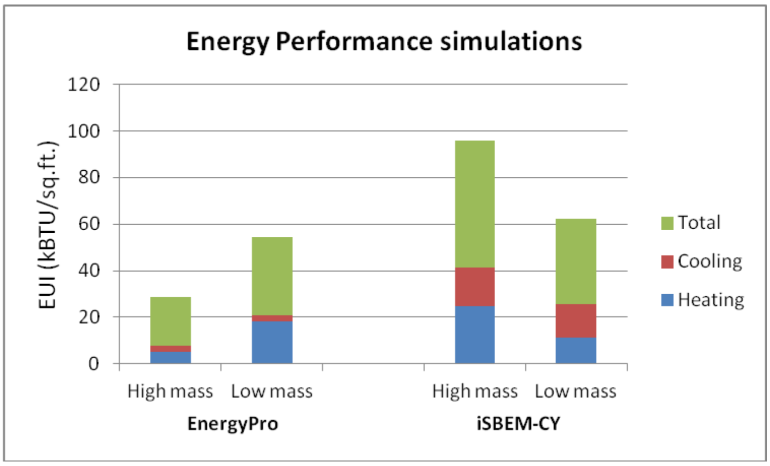


Figure 6 Energy performance simulations.

Table 3. Software input comparisons

System	EnergyPro	iSBEM-CY
Engine	DOE 2	SBEM
Weather files	TMY 3	Climate file from the software
Geometry	Same geometry	Same geometry
File type	.bld	.nct

COMPARISON OF THE SOFTWARE

A comparison among the two code compliance software has been performed. Similarities, differences and their limitations have deen identified:

Similarities

Both EnergyPro and iSBEM-CY were used for code compliance verification of residential and non-residential buildings.None of them showed a graphical representation of the building. None of the software is a design tool.

Differences

The iSBEM-CY software does not use .xml files for the model design but .nct. As a result, it was not possible to import and use the same project files between the software. Instead they had to be designed separately in the iSBEM-CY. It generates though .xml files for the official submission to the Register. The iSBEM-CY requires a SHW (Solar Hot Water) system since it is required by law. In EnergyPro the SHW is optional. For the purpose of this study, SHW was used in both cases. In EnergyPro it is not required to add an HVAC for cooling or heating. A fact which can give a better understanding of effect the buildings elements have to its performance. The two software use different units: EnergyPro uses the imperial system (IP) and the iSBEM-CY the metric system (SI). Regarding the result outputs, EnergyPro according to the EUI shows % of savings compared to the Title 24. iSBEM-CY generates the EUI and categorizes the building between the A to F range, where A the most efficient. EnergyPro and iSBEM-CY do not have the same options of adjusting the elements and building systems.

Limitations

For the iSBEM-CY, there are several settings which need to be adjusted in the Control Panel before running the program: for example, changing the "Regional and Language Settings" to United Kingdom, and changing the "User account settings" to "Never Notify". If these settings are not changed, the software will not run properly, and will fail to make the calculations and generate the reports. iSBEM-CY has a limited library of building elements and systems compared to EnergyPro. It is not currently possible to input the envelope's thickness manually. Therefore, it was not possible in the iSBEM-CY to evaluate how it calculates the effect of the thermal mass on the building's performance.

CONCLUSIONS

One of the most important findings in this study is that high mass buildings are more energy efficient in Los Angeles and in Cyprus the low mass. Taking into consideration the graphs **as shown in Figure 1 and Figure 2**, we could identify that more months are heating dominant than cooling in both locations. According to Climate Consultant, HEED and EnergyPro High mass residential buildings are more efficient than the low mass buildings in this climate. The EnergyPro and HEED results confirmed it. The Cypriot vernacular architecture and current construction materials applied also reinfornce the use of high mass materials as more efficient. Therefore, building materials with high thermal mass are suggested as a passive strategy for enhancing the building performance in this climate. The iSBEM-CY results contradicted these conclusions and consequently further studies should be carried in regards to iSBEM-CY to evaluate its outputs.

Futhermore, both the High and Low mass models passed the EnergyPro with 24% energy savings compared to Title24. Similarly, both the High and Low mass models passed the iSBEM-CY and were rated as "B" in their performance. EnergyPro counts thermal mass into its calculations. In contrast for iSBEM is not clear at what percentage its being calculated since the high mass had greater energy consumption compared to the other software. The attempt to simulate the models without an HVAC was possible in EnergyPro. iSBEM-CY cannot proceed to the calculations without an HVAC system. The assumption is that the developers of the software did not want to allow certification without an HVAC since the climate it Cyprus makes a mechanical system mandatory. Finally, Title 24 is more stringent than the Cypriot Energy code.

For Future works, a more extensive research with the iSBEM-CY software in order to obtain a clearer understanding of how the thermal mass is being perceived and calculated. Finally a comparison of the high and low mass models in other software could be used for validation of the results.

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Architectural Design: form follows sustainability?

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ABSTRACT

This paper describes different technological and architectural designs developed as the 2013 fall term project for the studio "Architectural Design VII" in partial fullfilment of the Architecture and Urbanism undergraduate programme belonging to the Federal University of Rio Grande do Sul, Brazil. The pedagogical aim of this project was to stimulate students to achieve high-level technological results along with expressive architectural solutions. The chosen case study was a residential unit ranging from 60sqm to 70sqm, able to house a married couple. The design brief was similar to the one adopted by the competition Solar Decathlon, held in the USA, Europe and China. The Studio methodology consisted of three steps: shape concept, performance evaluation and technological and architectural refinement. The shape concept is an exercise addressed to support the emergence of creative shapes with the contingent risk of getting unpredictable technological results; the following step consisted of the proof-of-concept of the house's energy autonomy, whereby the students were asked to demonstrate the project's electrical energy consumption and its capacity to autonomously supply at least the equivalent amount of energy. The performance tests involved evaluations related to natural lighting and thermal balance, daily and annual energy balance and reciprocally, the contribution of renewable energy and input sources such as photovoltaic cells and rainwater collection. In its final stage, the term project featured the refinement of the conceptual architectural design focusing on the integrated design of three building systems (structural, construction and installations). As a result of the term, it was observed that the adopted methodology produced reliable results for the pedagogical purpose in the fourteen projects presented, however the final stage may require more temporal importance in the schedule of the discipline.

1. INTRODUCTION

This work aims at describing the architectural design process using different technological and architectural designs developed during the 9th semester of the five year undergraduate program in Architecture and Urbanism at the Federal University of Rio Grande do Sul, Brazil. The main pedagogical aim of this term project is to encourage students to achieve high-level technological results along with expressive architectural solutions (Corrêa & Cruz, 2012). The chosen case study was a residential unit, 70 sqm, home for a married couple, and with a design brief similar to the one adopted by the Solar Decathlon (U. S. Department of Energy (1), 2014), held in the USA, Europe and China.

A previous evaluation of certain architectural solutions form the Solar Decathlon had raised the question about the limitation of sustainable homes regarding their form. Therefore, the term's challenge was to answer the question as to whether it would be possible to design an expressive architectural shape

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while maintaining a consistent relation between form and environmental performance, specifically the balance between energy consumption and production. This assessment is based on the assumption that sustainability issues naturally cause considerable modifications in the architectural language of the designed houses. The need to use photovoltaic and solar panels, new building materials as well as assembly and disassembly techniques and last but not least, the need to optimize the architectural form in order to maximize the reception of solar radiation destined to create major implication in the final designs. It was observed that a significant number of projects featured very conventional house designs concealing the visual impact of the technical elements responsible for the environmental performance of the house. From the students' points of view, various Solar Decathlon solutions – although featuring high scores according to the competition standards - did not introduce any particular contribution regarding their respective architectural form. All this reasoning has led to the question of how to achieve a good and optimized architectural design standard along with an optimized energy performance. Consequently, the problem of how to evaluate the students' designs, when considering the consistency between sustainability issues and architectural form, arised. In order to accomplish this goal a pedagogical strategy has been set whereby a) the students were asked to start from an architectural vocabulary inspired by sustainability issues such as natural forms used for solar radiation capture, b) the students were submitted to an evaluation system which provides them with a permanent assessment during their design process in relation to the studio's theme, i.e. the consistency between sustainability and architectural form, among others. The 9th semester studio methodology consisted of three sequential steps or exercises: i) the development of the shape concept, ii) a proof-of-concept including computational performance evaluations of the proposed architectural shapes and iii) final technological adjustment.

The remaining paper is divided into four parts: In the first part, the three stages are described. The second part presents the evaluation system and its results are analysed. In the fourth and last part, some conclusions are drawn in order to clarify the limitations and point out perspectives of the adopted methodology.

2. THE THREE STAGES METHODOLOGY

2.1 Development of the Shape Concept

The shape concept exercise was intended to support the emergence of expressive shapes with the contingent risk of provoking unpredictable structural solutions and energy performance results. Other issues, such as gray water collection and treatment, energy consumption and building materials, were – at this stage – considered peripherally as indicated by the structured list of requirements establishing the main design goals to be developed at certain points of time during the term.

This first phase was subdivided into two exercises: in the first one, the students analysed one entry to the Solar Decathlon competition and, in the second exercise, the students developed their own shape concepts. The analysis of the competition's house was divided into four topics.

Varios aspects have been highlighted during the teaching, the first among those was the architectural language and to what extend it expressed the materials, technologies, equipments and strategies for the production and conservation of energy as well as the achievement of environmental comfort. The question is: Are the "green" characteristics visible or not? These features may exist but they might not be visible or distinctive.

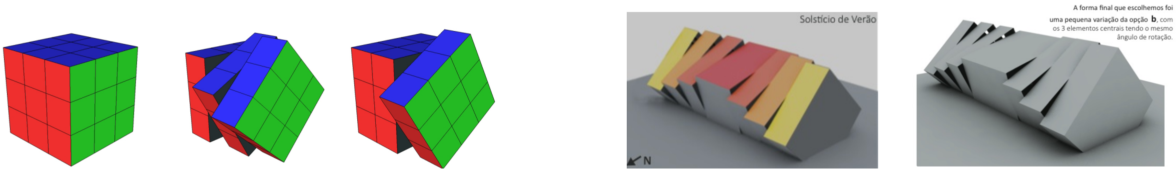
The second topic was about building technology and implies prospecting two factors: on the one hand the description of basic structural characteristics of the building, on the other hand the identification of novel components not found in conventional constructions. Building technology also involves materials, which are used for structure, waterproofing, foundations, thermal insulation, internal and external coating. The student should describe aspects of employed technological innovation in materials by linking these factors to corresponding goals, such as energy conservation, thermal comfort, cooling, among others.

The third issue involved the analysis of passive strategies and materials proposed for thermal insulation on horizontal and vertical planes. The shape, size, position and orientation of the openings and sealing elements also should be presented and the students were supposed to verify the way each element contributes to the thermal and visual comfort of the analysed project.

The fourth focus, denominated Ergonomics, was related to the technological innovations articulated throughout the arrangement of spaces and the flexibility offered by furniture components. This variable was intended to assess different levels of ease of use during the operation of spaces such as kitchen, bathroom, living room and bedroom by the end-user.

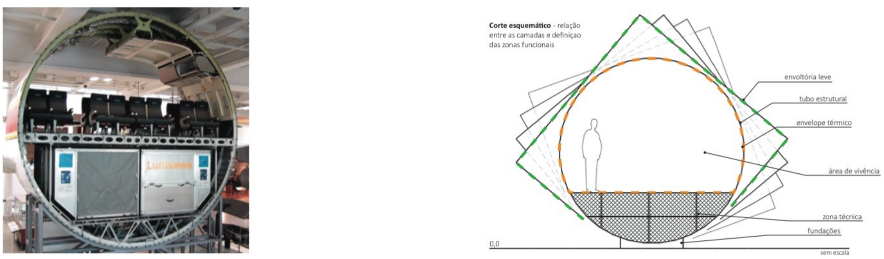
The second exercise was refered to as “conceptual shape”, which would be used by the students during the term’s subsequential time. Its purpose was to encourage the students to research more creative concepts, in a process which may require taking a step backward to achieve the principles of sustainability. The use of materials, technologies, devices and strategies intended to produce and maintain energy, as well as achieving a suitable level of environmental comfort may generate a relative tension between the architecture of the building and the need to achieve one or more specific performances. The authors sustain the hypothesis that the process of challenging freedom of expression on the one hand and a technological and environmental performance on the other will intrinsically produce a pedagogical gain.

The shape concept exercise took about two weeks, and the students were asked to respond to the four major areas already established in the previous exercise: the architectural language, the structural system and materials, sustainability and ergonomics. This strategy was useful to inform the role of these different aspects visually and allowed greater control, increasing the likelihood of design success during these first steps of the form finding process (Turkienicz & Westphal, 2012). Using a storyboard strategy, the students described the main design ideas by means of images and text, which reflect the origins of the formal concept (Aroztegui, 2013). The resulting storyboard - describing the relation of chosen objects to the basic ideas of sustainability, such as mainly energy production or conservation - has led to the student’s preliminary design (Fig. 1, all future figures refer to the project from the same authors). In sequence, the students proposed transforming specific geometric concepts of the generating object, suffering mutations and evoluations in such a manner that it finally incorporates aspects of form as well as structure, but also left a appropriate degree of uncertainty in order to accept future peculiarities regarding the envelope, materials and ergonomics (Fig. 2).



a) b) c) d) e)

Figure 1 Student work “Solar House”: (a) concept based on the Eno Rubik magic cube; (b) and (c) rotations of the slices providing different positionsfor better insolation; (d) summer insolation; (e) the final form (students: Fernando Netoux, Rodrigo Lima).



a) b)

Figure 2 Generative strategy: (a) the insertion of an inner tube inspired by the Airbus’s structure; (b) external shape: the seventeen square structures are rotated 10º in relation to the adjacent ones, the exterior components work as an external envelope.

2.2 Proof of Concept

The second stage consisted of the proof of concept regarding the house's performance whereby the students were asked to demonstrate required inputs, outputs and other specific performance values. Throughout the presentation of the project's energy, thermal comfort, and natural lighting performance, it was required to demonstrate the consistency between form and environmental performance, at a point when the preliminary study had been concluded. The results were obtained by means of computational simulations and aided stipulations of contributions of the photovoltaic panels and rain water collection. The proposed building assessment creates a quick preview of the concepts, such as electrical energy consumption, thermal comfort and natural lighing, based on assumed simplifications or annual, monthly, daily, and hourly data derived from a global database of weather information. By using these results the students may improve their designs (Bergman, 2012). The stipulation and simulation of environmental variables required a theoretical base on specific technologies, which - in the begining of the term – were desseminated during a series of lectures on Structural Building Systems, Photovoltaics, Passive Houses, Efficient Lighting, Environmental Comfort and Waste Water Treatment.

In more detail, the results were achieved using dynamic spreadsheets and the computation tool Autodesk Ecotect Analysis (Autodesk Inc., 2014), importing the model either from Google/Trimble SketchUp or from CAD. This tool was chosen due to its free access and ease of use, also guaranteeing quick results due to short processing times. Another alternative would be EnergyPlus (U. S. Department of Energy (2), 2014), but it use was discarded because time constraints are making it impossible to guarantee the student's necessary theoretical and practical capacitation.

The students were able to determine whether the model was receiving suitable natural lighting levels using the Daylight Factor analysis (Fig.3a). In other words, a model with satisfying results is very likely to achieve savings of artificial lighting during daytime hours. Furthermore, the analysis of the Incident Solar Radiation contribuited to the evaluation of the project's potential to produce and store solar energy consequently resulting in the capacity to heat the interior space during winter and attending the need for shade in the summer month (Fig. 3b, 3c, 3d). The thermal comfort analysis uses discomfort expressed as Degree Hours in order to evaluate and compare the projects' performance (Fig. 4).

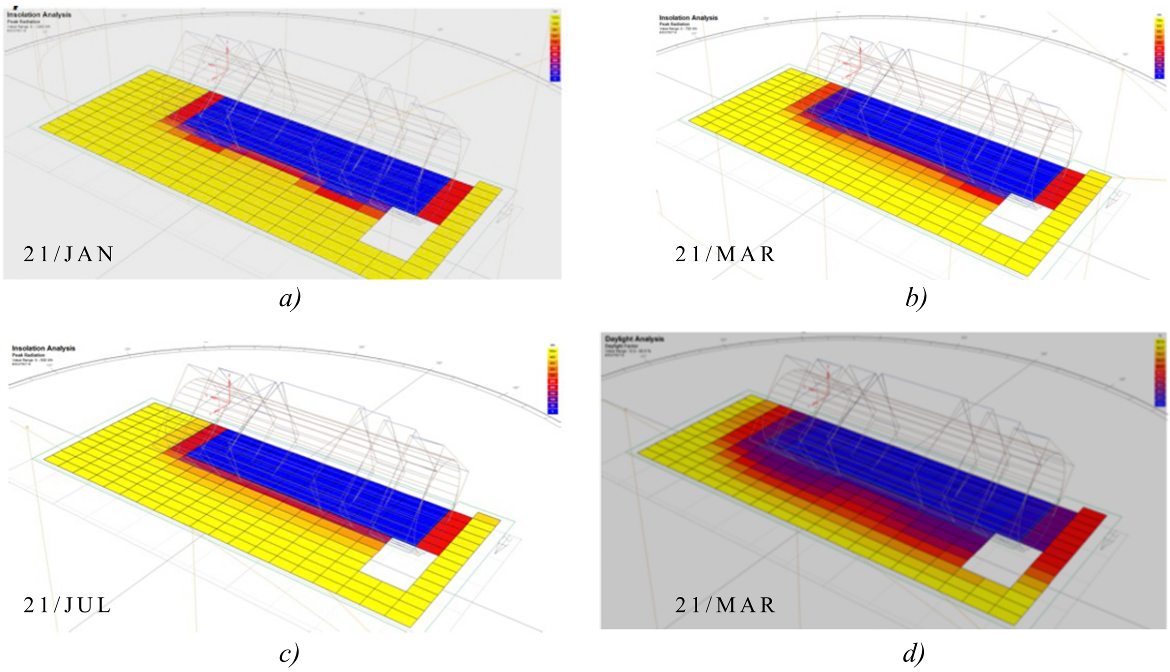


Figure 3 *Solar Anlysis: (a) daylight analysis shows daylight factors between 2 and 10% in the interior zone, (b) solar radiation analysis for 21/JAN, (c) solar radiation analysis for 21/MAR, (d) solar radiation analysis for 21/JUL.*

The energy balance evaluation should consider the entire amount of electricity consumed by appliances such as electric lighting, refrigerator, dishwasher, washing machine, and microwave oven as well as the energy produced by renewable sources such as photovoltaic panels (Fig. 5). The performance tests also involved the water balance created by the comparison between the points of consumption such as showers, washbasin, toilets, kitchen sink, dishwasher, washing machine and the water generated by the process composed of rainwater as well as gray water collection and respective treatments. In more detail, the autonomy from external fresh water sources is in most cases addressed by using stored and treated gray water for irrigation, cleaning and toilets. Indeed, the harvested and treated rainwater is reused for drinking and washing purposes.

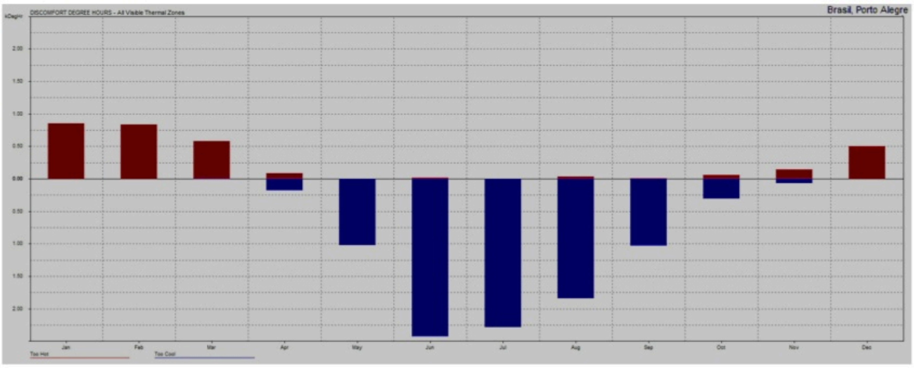


Figure 4 Annual Discomfort Degree Hours: shows a total number o 3138.3DegHrs of discomfort (too hot), 9176.6DegHrs of discomfort (too cool), totalizing an annual total of 12314.8DegHrs, thereby the design should be refined for the winter month of the southern hemisphere.

ANNUAL ENERGY PRODUCTION							
	equipment	rotation south	horizontal tilt	area	efficiency	use	annual prodcution
	[]	[°]	[°]	[m²]	[%]	[%]	[kWh/a]
PV	painel 01	180	20	8,10	18,30	100,00	1413,26
PV	painel 02	180	20	8,10	18,30	100,00	1413,26
PV	painel 03	180	30	8,10	18,30	100,00	1413,26
PV	painel 04	180	30	8,10	18,30	100,00	1413,26
PV	painel 05	180	40	8,10	18,30	97,00	1370,86
PV	painel 06	180	40	8,10	18,30	97,00	1370,86
PV	painel 07	180	50	8,10	18,30	93,00	1314,33
PV	painel 08	180	50	8,10	18,30	93,00	1314,33
						TOTAL =	11023,44

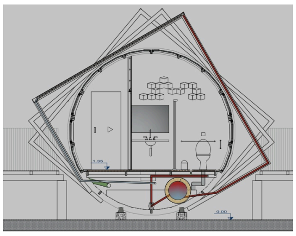
ANNUAL ENERGY DEMAND				
	equipment	hourly demand	duration of daily use	annual demand
	[]	[kWh]	[h]	[kWh/a]
mandatory	geladeira com freezer	0,07	24,00	649,94
mandatory	cooktop / forno / fogão	3,00	1,00	1095,00
mandatory	maquina de lavar louça	1,35	1,00	494,52
mandatory	maquina de lavar roupa	1,00	1,50	547,50
mandatory	chuveiro	0,42	0,50	76,53
mandatory	ar-condicionado	1,40	3,00	1533,00
mandatory	somatório iluminação artificial	0,23	3,21	269,84
facultative	computador	0,09	1,00	32,85
facultative	chuveiro(s)	0,40	0,50	73,00
facultative	bombas de aqua	1,11	0,00	0,00
facultative	ventilação forçada	0,00	0,00	0,00
facultative	motores para automação	0,00	0,00	0,00
facultative	televisor	0,06	2,00	43,80
facultative	aparelho de som	0,07	2,00	51,10
facultative	maquina de secar roupa	3,50	1,00	1277,50
facultative	aquecimento / calefação	0,00	1,00	0,00
			TOTAL =	6144,57

ANNUAL BALANCE	
ANNUAL DEMAND	6144,57 kWh/a
ANNUAL PRODUCTION	11023,44 kWh/a
	4878,87 kWh/a

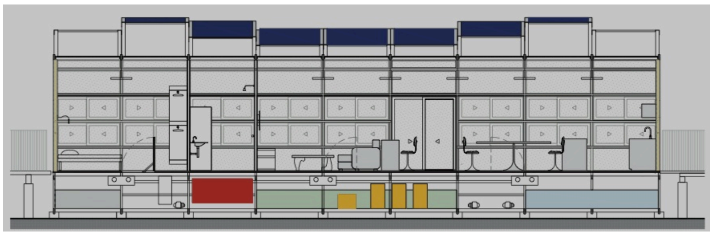
Figure 5 Energy Balance: a positive balance was achieved (blue), with a greater amount of energy produced (green) than consumed (red).

2.3 Final Technological Adjustment

In its third stage, the term project featured the refinement of the architectural design through the integration of aspects related to structure, construction and installations. This step emphasized the importance of correlating the architectural language with the technological demands. In other words, the students were encouraged to propose architectural solutions, which absorbed the technological demand (Fig 6). This phase enabled formal refinement, since at this point the student had the quantitative data needed to improve or change the qualitative aspects of his/her design. Energy consumption tables with negative results meant that energy demands had to be reduced or, alternatively, production had to be increased. As the production of energy is basically the result of the performance of the photovoltaic panels, it may be necessary to increase the efficiency of the product, optimizing the position related to the solar incidence or implementing a larger area of panels. In this final stage, the term project featured the refinement of the conceptual architectural design, which can enhance the conceptual form, but needs to additionally consider the building as it isconceived as a whole system, where the structure integrates the installations and the constructive system solves every different type of joint and/or interface between all components. For example, the structural systems as well as the sealing components may be designed as part of the solutions for HVAC, electricity and hydraulics systems (Fig. 7).

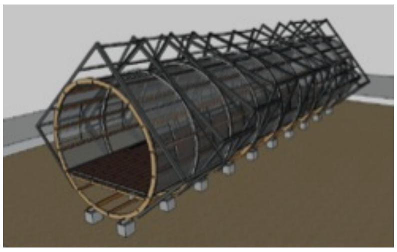


a)

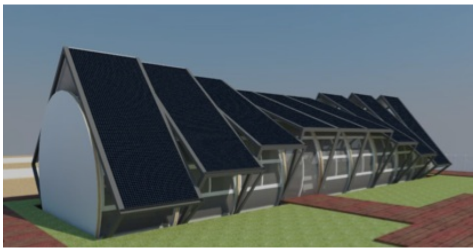


b)

Figure 6 Sections: (a) hot water tank supplied by the solar thermal collectors integrated into the eternal envelope's structure; (b) technical equipment such as drinking-water tank, gray water tank, non drinking-water treated water tank, gray water treatment tank, black water tank, hot water tank, water pump, and solar inverters are placed under the house's flooring.



a)



b)

Figure 7 Technological adjustments: (a) the tube section forms the structural system of the house; (b) the final design.

3. THE EVALUATION SYSTEM AND RESULTS

The evaluation results showed that, during the first steps of the form finding process, the students obtaining above average scores for the conceptual integration of elements responsible for the environmental control presented the best solutions for the architectural and technical realization of the building envelope as well. The detailed resolution of the architectonical elements, such as photovoltaic panels, solar thermal collectors, solar protection and/or insolation, has been handled best by students who had managed to integrate these concepts into the overall idea at the beginning of the course. The same group of students would be expected to achieve the best performances. However this is not confirmed by the results at hand. Throughout the performance analysis of these student's designs, the results have no obvious correlation with either the successful integration of the concepts into the idea or their detailed solution in the architectural elaboration of the project. A typical example is the balance between solar gains for daylighting on the one hand and heat accumulation caused by the same source of energy. These aspects involve a combination of profound studies of theory and practical experience, which students typically do not present at this given academic level.

When analysing the results by standard deviation for the categories related to the architectural elaboration of the building envelope as well as the resulting performance, two main observations can be made. Firstly, the lowest deviations are found in the categories regarding the photovoltaic panels and the energy balance, respectively; these categories also present the highest average scores. Secondly, by far the greatest deviation among the categories for the building envelope was found regarding warm-water production, while for the performances most differentiated scores have been obtained for thermal comfort, which consistently presented the lowest average scores. The first fact can be explained by prior education and the project's focus in this specific criterium. An enquiry, although performed during a later semester, shows that students consider solar energy as the topic on which they have the most complete knowledge base compared to other technologies like thermal power generation or waste water re-utilization. Starting the semester with the analysis of case studies from the Solar Decathlon has predictively led to concepts and consequently technical solutions that are fit for this type of technology and have resulted in well elaborated energy generation mainly based on it. The second co-relation shows that the students either did not have sufficient prior knowledge of certain other technologies, such as warm water generation, or were not able to acquire such knowledge either from the theoretical lessons, from examples such as the analysed case studies or on their own during project development. Especially in the case of the thermal comfort the deviation must be explained by the low scores some groups obtained with wrongly executed simulations or erroneous representation and misinterpretation of the results they obtained with Autodesk Ecotect.

4. FINAL CONSIDERATIONS

In general, it may be affirmed that throughout the 14 projects turned in at the end of the term, the proposed methodology has ensured a relative homogeneity of results with respect to the pedagogical objectives outlined at the beginning of the semester. The evaluation of pedagogical procedures indicated the importance of emphasizing a constructive awareness even in the initial stages of the design process. Although the designs developed in 2013/2 reached high levels of formal exploitation (Fig.9), the projects show a difficulty in reconciling this exploitation, especially with the constructive systems employed.

In more detail, the inicial phase of the course, dedicated to the student's analysis of one project from the Solar Decathlon competition, functioned as an introduction to the methodology developed for the course. Nevertheless, the authors noted that the students did not assimilate sufficient knowledge during this stage in order to incorporate innovative solutions from the analysed projects into their own. As improvement, the authors will try to implement the use of fisical models of the analysed projects in future semesters to improve the three-dimensional understanding of the implemented solutions and consequently raise the level of detailed understanding of the system as a whole. Another desired enhancement would be additional time for the refinement of the project based on the performance results obtained. Two weeks dedicated to this revisitation of the proper project would not only sharpen the understanding of the results itself, but also strengthen the understanding of the intertwined processes of sustainability, architectural form, and employed materials.

Finally, the integration of the architectural language, the building energy consumption and other described sustainability issues, involving building systems and requirements, have both process-related and aesthetic aspects. The concern with the process of all parts of the design emphasizes that sustainability is at the core of the design process together with other design parameters such as function, structure, construction and installations. The teaching strategies used is leading the authors to develop a methodological path to design, evaluate, demonstrate and qualify the object at all design stages, from conception to installation. The exploration of architectural language during the conceptual phase and preliminary studies of the house gave the students an opportunity to bind architectural forms to the goals of environmental performance. The three-step methodology has helped students to expand their awareness of the risks of designing without attention to environmental aspects. At the same time, the manipulation of performance models throughout computational tools allowed the students to feel confident in their environmentally tested designs.

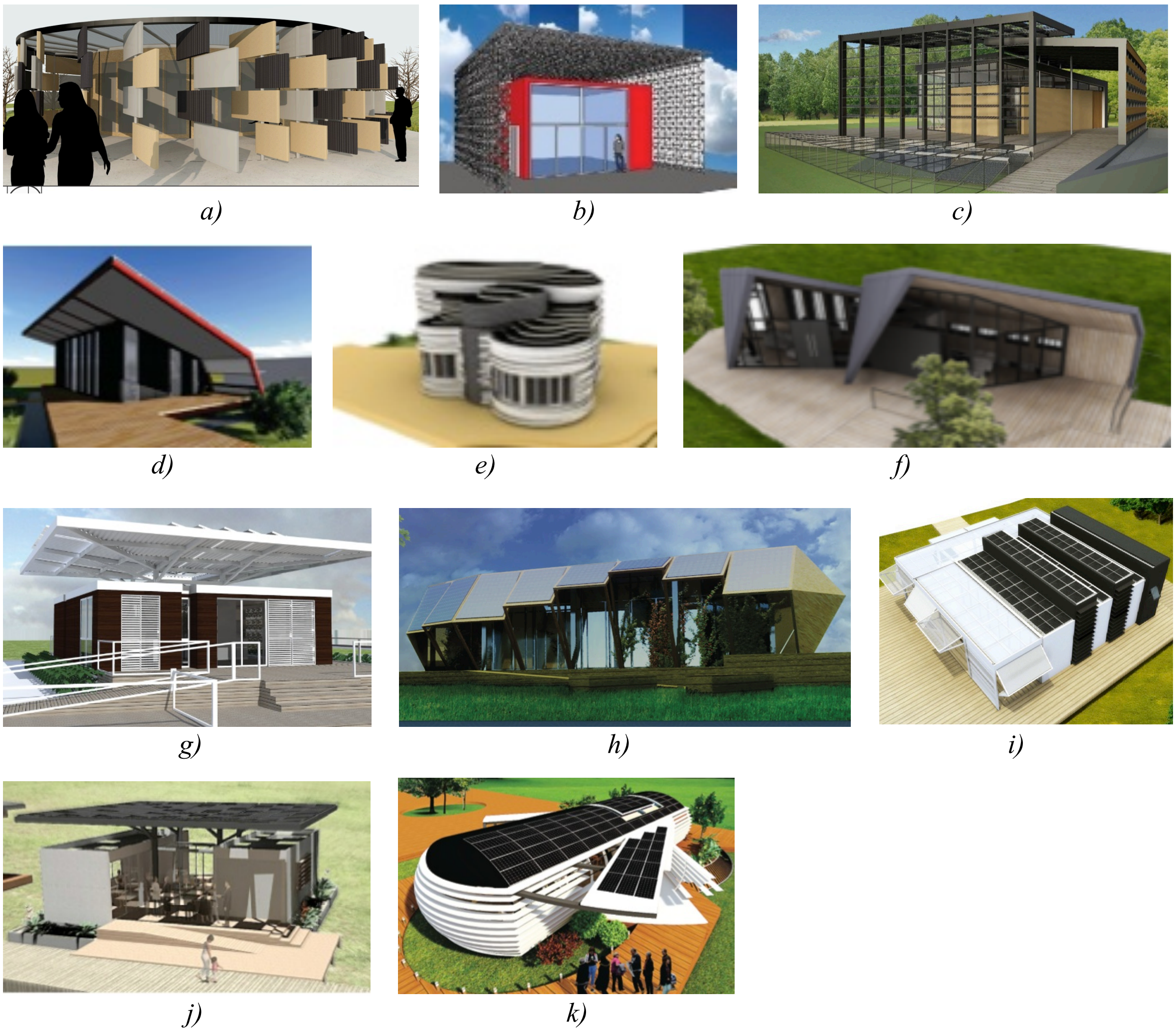


Figure 9 *Results: (a) Shadow House; (b) Cube House; (c) Gigogne House; (d) Fold House; (e) Cell House; (f) Origami House; (g) Tree House; (h) Energy House; (i) Allegro House; (j) House T; (k) Vitori House.*

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Technical and Culturally Sensitive Solutions to Foster Sustainable Housing in Southern Angola

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ABSTRACT

Studying housing solutions demands a multidisciplinary concern in order to come up with comprehensive answers able to account for physical, social and cultural needs. It is, therefore, fundamental to bring up those needs into the housing creation process.

In the City of Ondjiva, in Southern Angola, as throughout the world we can observe a lack of habitability in its slum areas, associated to the existing economic conditions. In most cases the settlement isn't provided with basic infrastructures, does not respond adequately to the climatic demands, which leads to the development of unhealthy environments. Additionally, the house in the city follows European or contemporaneous models which don't produce culturally oriented answers for the local inhabitants. As a result, the poorest housing areas are characterized by two major inadequacies: constructive and cultural.

This proposal intends to bring into the discussion the need for architectural solutions that are culturally sensitive (user-oriented), as solely technical solution appears to be detrimental to the diversity of ways of life characteristic of contemporary cities. Furthermore, it intends to alert to the need of exploring new technologies in order to turn the expertise accessible to the housing construction current actors, in a context of great poverty.

The goal of this proposal is to create an innovative IT tool, an Expert System which will integrate both results from environmental-behavior studies of a specific cultural group, and sustainable design solutions. It will be produced as a tool to help in the design of individual housing profiles and consist on the construction of a System of Relations between three pre-established group of settings, cultural, everyday life activities and architectural, in order to find a multidisciplinary response for the problematic of housing inadequacy and lack of constructive, comfortable and hygienic conditions.

INTRODUCTION

This paper is based on a research done under the PhD program in Architecture at EPFL and IST, focused on the search for alternative solutions to foster sustainable housing development in Southern Angola. The main goal of this research is to improve housing design and construction processes in slum areas, where self-building prevails; it explores the use of new technologies in order to make expertise accessible to the housing construction current actors, in a context of great poverty. The research is addressed to the case study of self-built housing in the City of Ondjiva in Southern Angola, giving special attention to the cultural aspects of the Kwanyama People (local majority group) and to the region's climatic conditions.

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It stands on the following **premises**: *The poorest housing areas in the City of Ondjiva are characterized by two major inadequacies: cultural and constructive. It is therefore, urgent to find adequate cultural and technical solutions to foster sustainable housing construction.*

Ondjiva, as a City, was implemented in 1915 by the Portuguese military forces and it was designed and developed according to European models as well as the housing models within the City. After almost one century it can be observed that the urban areas have developed in complexity and dimension. Levels of acculturation have also increased, but despite this process of change since 1915, the existence and search for traditional housing models persisted; strong traditional traces are still present all over the city, particularly in the poorest housing areas where traditional values prevail, reflected in daily practices and in the living space. Simultaneously the housing construction in the City poorest areas lacks of sufficient habitability conditions due to the lack of construction knowhow and due to the economical conditions in which the majority of the population arrives at Ondjiva, not allowing them to hire a constructer or to have access to better construction materials.

Cultural inadequacies

There is a great body of literature on Ondjiva and the Kwanyama region which brings to the attention, among cultural, socio-economic and migration issues, facts about the construction of vernacular housing, to be considered in this work (Estermann 1961, Monteiro 1994). There is however no information on the issue of slums in the City of Ondjiva, besides the government urban plans and reports which present a general overview on the main construction and architectural characteristics in the City (Government of the Province of Cunene 2005).

In the City of Ondjiva, self-built houses correspond most of the time to two main aspects: an urgent need for shelter (built according to the scarce economic resources) and to the perception that each one has about what should be a "better house". Usually a better house corresponds to the houses of the wealthier people, houses constructed with more durable materials and following standard typologies (European models are the most followed). As a result, a self-built house in the poorest areas is generally a parallelepiped simply subdivided in the possible number of divisions (the most common are 2 or 3divisions **as shown in Figure 1**).

Figure 1 Examples of housing construction in the poorest housing areas of Ondjiva

Nevertheless, if not in terms of house form, we find a lot traditional traits within the City, especially in the exterior arrangements and in the way people inhabit both the interior and exterior spaces. For example, the internal layout of the house consists mostly on bedrooms, which for the most traditional people, are only used to sleep at night; during the day, the interior of the house is rarely used. Instead, there are other structures that are constructed in the exterior of the house to be used during the day, which replicates the traditional habits of a vernacular housing: covered structures which serve as living rooms, named Okatala (even if sometimes there is an internal one,) or external kitchens, also with special specificities, named Epata. Therefore, where the main house building (generally a family house is constituted by more than one building) tends to follow the city social patterns, annex structures are the ones often built for specific traditional proposes or activities. As such, the main building assumes a "false centrality", a symbolic and representative centrality, while the annex structures embrace the real family needs, tasks and everyday life practices, full of traditional and cultural significance. This conflict of social aspirations and customs (on one side the desire for wealthier houses, according to the contemporary society patterns and on the other side the persistence of traditional values and practices) leads to great incoherence in the self-built housing structures and spaces.

Constructive inadequacies

Along the general lack of infrastructures related to the economic conditions, most of the buildings do not respond adequately to the climatic rigorous demands, offering unhealthy environments.

The climate of the Kunene province, where the City of Ondjiva is located, is essentially of the semi-arid type, with the rainy season coinciding with the summer months (when the average temperatures are higher). The average temperatures in the region are close to the ASHRAE Comfort Standards (ASHRAE, 2005), having an annual average temperature of around 23°C. However, in terms of maximum daytime temperatures, these are often outside conventional comfort boundaries, as well as the large temperature variations between night and day, reaching amplitudes greater than 15ºC. The absolute minimum value recorded for Ondjiva is -2,3°C in June 1944 and the maximum values of 40.5°C and to 39.9°C were achieved in November 1941 and September 1964, respectively (Govern of the Kunene Province, 2005). Daytime temperatures around 30°C or more are frequent, with a drop to 10°C during the night, meaning that extreme conditions are verified, which can potentially lead to (excessive) energy consumption through the use of HVAC - unless oriented bioclimatic design strategies are applied.

In a study made under the Sure Africa project's investigation (http://www.sure-africa.org) the conventional comfort zones of ASHRAE were overlapped with the zones of influence of the various passive techniques based on research conducted by Givoni (1969). The results showed that according to its climatic characteristics, Ondjiva is under the influence of four passive cooling techniques such as day and night ventilation, thermal inertia, evaporative cooling and humidification. There is a period where heating is needed, which can be obtained in a passive way by taking advantage of solar energy, for example by orientating the building according to the sun projection or by a correct sizing of the glazed surfaces (Correia Guedes and Aleixo, 2011).

The current self-built buildings in the City usually do not present any of these characteristics. On the contrary, they commonly have no enough natural ventilation, no sufficient inertia, adequate shading or a correct solar orientation. The solar orientation is random except when it is related with traditional aspects, placing the main entrance at East. **Figure 2 show** the thermal and humidity performance of 3 different housing buildings within the city, for the period of one day; the respective buildings, among 17, were monitored with data loggers, measuring the interior and exterior temperatures and humidity values in intervals of 30 minutes, between June and July of 2013.

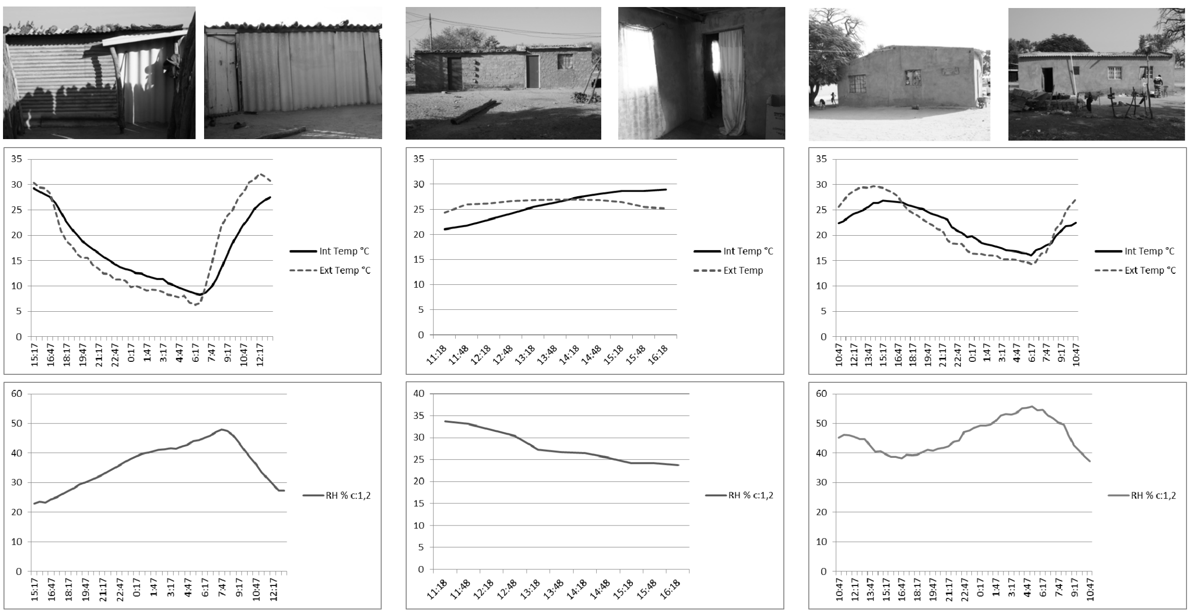

Figure 2 Temperature and Humidity monitoring of three buildings in the City of Ondjiva

These buildings represent the worst, medium and the best types of self-building construction in the City in terms of thermal comfort. The first one, **at left in Figure 2**, corresponds to an urgent need for shelter and it is composed of one room only, built with zinc boards, fibber cement boards and wood or pick to stick structures. The second one, in the midle, corresponds to a medium solution, built with handmade cement bricks and uninsulated zinc boards for the roof. The third one, at right, corresponds to an improved and phased construction, which started in 2000, with the construction of two single rooms; in 2001 a small interior kitchen and w.c. were added and in 2005 the living room and one sleeping room were built. The building materials differentiate from ruins remains (stone, bricks, etc) in 2000, handmade adobe bricks in 2001 and cement bricks in 2005, and the roof is made of simple zinc boards with no insulation. The exposed measurements correspond to the part constructed in 2005.

As shown in Figure 2 the 3 buildings have a weak thermal performance. Work made on building performances analyses for the City of Ondjiva (Correia Guedes, Aleixo and Pereira, 2011) show that some of the best practices for construction are:

1. Building optimum orientation: E-W axis orientation;
2. Minimum glazing distribution to East and West facades, 15% to 30% maximum of glazing areas in South and North facades, horizontal and vertical shading devices on East and West facades and horizontal ones on South and North facades are passive strategies which improve the building behaviour;
3. Rammed earth walls on existent buildings have better performance than the usually used concrete block without insulation;

In summary, the house construction in the city doesn't present oriented answers for either cultural (social, community and everyday activities aspects) or the buildings' comfort needs. The buildings where the largest part of the population lives in Ondjiva, particularly in suburban areas, are still very poor, with low levels of habitability; most of the times, they are buildings that respond to an urgent need for shelter, not being constructed to last and which lack of almost all the support basic infrastructures. This brings us to the next point: "what is needed?"

THE NEED FOR WHOLE AND MULTIDISCIPLINARY ANSWERS

Solely technical solutions can be detrimental to the diversity of ways of life characteristic of contemporary cities; interior confortable spaces will not be enough if they won't allow the continuity of cultural specificities. For example, the houses built recently in the City by the Government for the community do not offer proper external shaded spaces for group reunions, exterior kitchens, separated dining spaces, separated husband/wife sleeping rooms neither respond to the strong hierarchies within the family. These are specificities of traditional cultural patterns that when neglected may have serious results (Rapoport, 1969). Indeed, it is in the outside space that the most traditional activities take place and annex structures are often built by the inhabitants to meet the specificities cited above.

There is an urgent need to bring whole and multidisciplinary answers to the housing processes in the city of Ondjiva, in particular to the self-building one, instead of trying to stop those processes or change their current actors. Only by reaching the individual actors is it possible to find a global answer for the improvement of the living conditions. As we suggest, it is fundamental to relate culture to the built environment on the search for culturally oriented housing solutions; but the central problem resides on how is that relation established and in the variables that are applied in the relation process: *How to define the settings that make up culture? How to understand the world views and values standing behind what is called culture? How to understand which values should or not prevail in the future housing design? And finally, how to relate culture with technology?*

Culturally Sensitive Approaches and Technological Answers

Culture has been one of the main concerns in the study of housing since the 1960's when several authors began looking to the built environment as a result of many culture influences. Assessing culture is particulary relevant when trying to analyse and evaluate its impact, in this case, on housing.

The Environmental-Behavioural Studies (EBS) model from Amos Rapoport represents an important tool in analysing which factors influence the house form, allowing to evaluate those factors and to measure them in order to understand how the build environment (housing) responds to their inhabitant's specific needs. The EBS model from Rapoport breaks down the influence of culture, on one hand as a group of social variables that can be measured within a System of Relations, and on other hand as an expression of lifestyle and values which leads to the activities happening in a specific space. For the author, the design of one space where a certain activity will take place corresponds to the specific arrangements which need to be done for the activity to happen, paying attention at the same time at how the activity is done, the meaning of that activity for the culture and its social or ritual significance (its latent aspects) (Rapoport 1988). The goal of Rapoport's EBS model is to provide a framework for the understanding and study of the group of settings which compose the Built environment, and for the establishment of a system of relations between those settings and the latent aspects of activities, leading finally to the "housing profile" (final result).

Existing works on culturally oriented housing studies are not yet completely applied to housing design. Indeed, the existing research is more focused on housing evaluation rather than new housing conception processes (see Khattab 1993 and Sungur & Cagdas 2003). On the other hand, there are multidisciplinary approaches on housing development, but almost all of them stand in one-to-one participatory relations between the architect and the future inhabitants (UNHabitat, Diébédo Kéré). That is perhaps the most correct and productive approach but it is difficult to implement in a context of massive self-building production, at least without changing its current actors. Designing for each individual is a difficult, if not impossible, task to achieve and it is impossible to think that it would be economically viable. Therefore there is an urgent need to think on alternative solutions to improve the existing poor housing conditions in the poorest housing regions in the World; not only multidisciplinary solutions but accessible solutions and of easy application in the context of self-building housing in slums. *How, then, to come up with a multidisciplinary solution easily accessible to the self-builders in a context of poverty and architects absence? How to share the knowledge?*

HOW TO MAKE THE KNOWLEDGE ACCESSIBLE TO THE SELF-BUILDERS IN A CONTEXT OF POVERTY AND ARCHITECT'S ABSENCE?

First, in order to develop integrative and oriented design, it is fundamental to understand which procedures are more appropriate to share specific information, and how to make this information comprehensive and fully applicable (Friedman 2003; Akrich 1987). As Yona Friedman suggests, other languages than sole formal one of architecture must be found, which must be *simple* (understandable and easy to use), *significant* (direct, clarifying which consequences are implied in one decision made according to the plan described through that language) and *interpersonal* (discard form expressions that can have different meanings to different persons) (Friedman 2003).

This proposal intends to build up a similar System of Relations to the one proposed by Amos Rapoport, which will relate three pre-established group of settings, cultural, everyday life activities and architectural, in order to be able to give specific answers to the housing construction. Plus, it intends to bring the System of Relations to the future inhabitant and the future inhabitant to the System of Relations, turning it user interactive, which is possible by the creation of an Expert System, an IT tool that will embed and support the System of Relations. It is important to remember that we are working in a context of architect's absence and where the house planning procedures do not include a prevailing housing design. Therefore the search for alternative solutions is based on the following postulate: *if we can't have experts orienting everyone's house construction, we can at least try to make the expertise accessible to everyone*. It is in this sense that the Expert System is created; it shall be able to replace the expert and transmit the knowledge to its users, in a *simple, significant and interpersonal* way. The Expert System will allow simulating specific housing profiles – at the same time bio-climatically optimal and culturally sensitive – as a way to combine the advantages of a face to face participatory process and an inproved building procedure.

The development of an Expert System

"An Expert System is one in which human Expert knowledge about a specific domain is encoded in an algorithm or computer system" (Luger 2004); "the core of an Expert System is the knowledge-base, a database in which the main domain-related intelligence is encoded. Such a database is typically populated using the knowledge of one or more human Experts (…) In addition to being an informative stand-alone resource, the knowledge-base is a critical component in the Expert System" (Lee and Andersen 2009). The knowledge base will be constructed according to the available data resources, that is either heuristics either experimental, either qualitative either quantitative. It will also be based in optimization methods or algorithms for building design decisions, as the genetic algorithm (GA) (Goldberg 1989). In the proposed Expert System the user will be guided through a step-by-step process in which programmatic and constructive directives definitions are gradually decided towards the user's goals while respecting the pre-established System of Relations between cultural, activity systems and architectural variables. As stated, this system is meant to be user-interactive, flexible, and oriented to the specific case of Kwanyama People building their houses in the City.

The **concept behind the System of Relations** is the systematization of the architectural thinking process when conceiving a house for a particular user. It is fundamental to fully understand the cultural and personal context in which the user lives to better understand the needs and wills towards his future housing; this is, to be able to define the group of settings (aspects) which compose the built environment and therefore the architectural form.

The System of Relations – one of the most fundamental research question at stake - will be reflected in a decision "tree" that after inserted in the Expert System and according to the user's input, will lead to the final Housing Profile (group of culturally, architectural and personal oriented directives for the housing conception). It constitutes the Expert System's knowledge base and it is built on the principle that every aspect/variable, within the climatic and constructive, cultural and activity system's contexts, has an architectural implication. The set relations are translated into a decision tree, which is constructed by accomplishing the following steps, **as shown in Figure 3**:

Step 1 – Defining the **aspects/variables** within the Kwanyama culture; aspects of the people living in self-built houses in the City and their everyday life practises, of the construction procedures, climate and local environment (social, economic and urban);

Step 2 – Understanding which **architectural implication** can each aspect/variable have;

Step 3 – Defining the **group of aspects/variables** within each architectural implication (as the group of settings that compose the architectural form);

Step 4 - Defining which **relations** within each group of aspects will influence the architectural form;

Step 5 – Defining the **procedures** that will allow, ultimately, establishing the System of Relations.

Step 1	Step 2		Step 3	
Aspect 1	Aspect 1 →	Implication A,B,C	Implication A →	Aspect 1, 4, 5…
Aspect 2	Aspect 2 →	Implication C, D, F, G	Implication B →	Aspect 1
Aspect 3	Aspect 3 →	Implication E	Implication C →	Aspect 1, 2, 5, 8
Aspect 4	Aspect 4 →	Implication A	Implication D →	Aspect 2
Aspect 5	Aspect 5 →	Implication A, C, E	Implication E →	Aspect 3, 5
…	…	…	…	…

Step 4		Step 5
Implication A →	Aspect 1 and 4 or 5	Calculation Procedures
	Aspect 1 and 5	Analytical Procedures
	Aspect 1 or 4	Decision Procedures
	…	Probability Procedures

Figure 3 Proposed steps to create the System of Relations

These steps allow constructing the System of Relations, which takes the path of a decision tree, **as shown in Figure 4** (a); in the decision tree the departure point is the step 3 (the step 1 and 2 allow achieving to this point) in the sence that the departure point is an architectural implication (house form, division, partition, roof, material, glazing, shading, etc); to arrive to the concrete parameters of that architectural implication or form, all the aspects/variables influencing the architectural form will be inserted in the tree. According to the user's opinion the aspects/variables within the decision tree will be accepeted or refused, and only the validated ones will be related in order to establish the final directives for the construction.

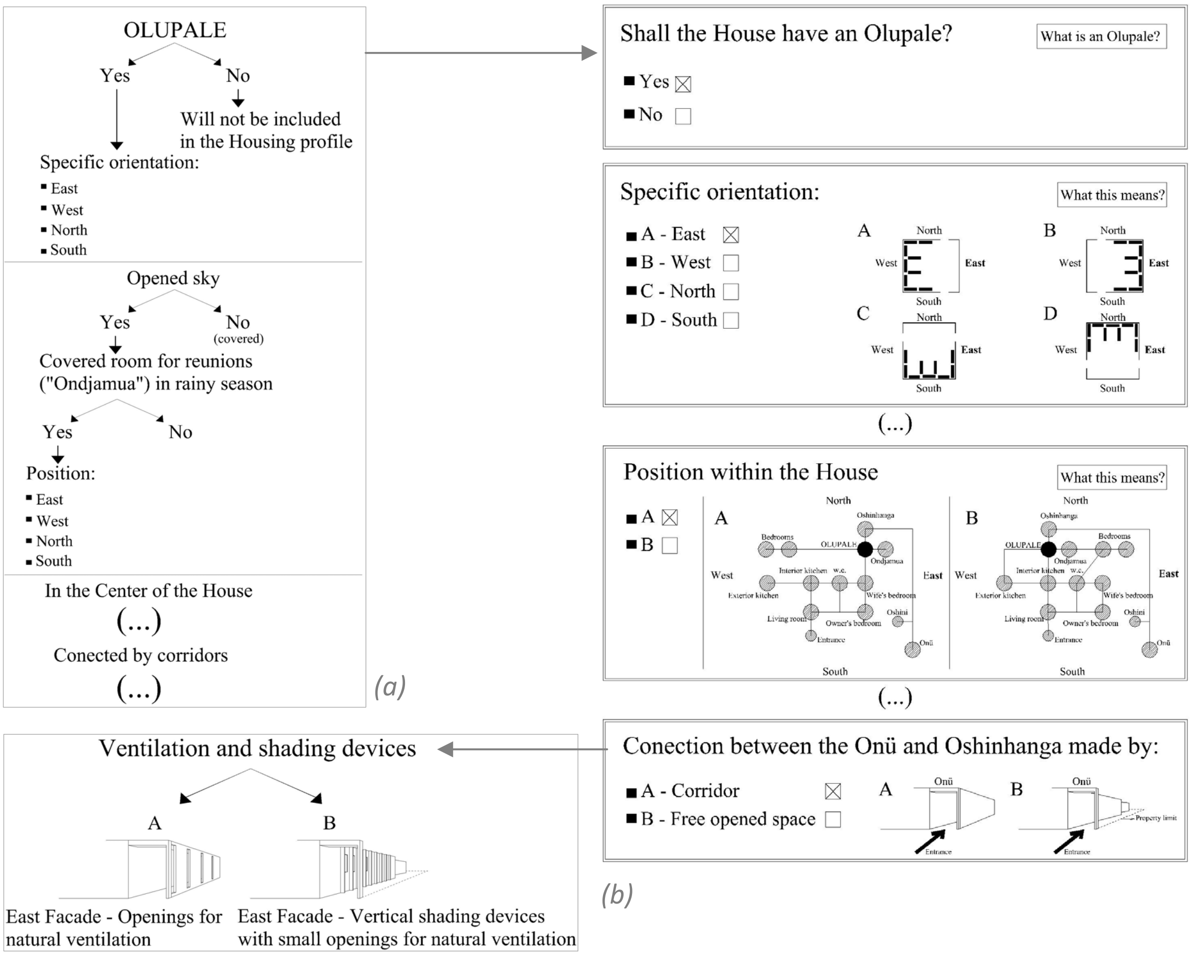

Figure 4 Part of the Decision Tree (Olupale: traditional living room) and (b) example of the Expert System layout (Onü: traditional main entrance; Oshinhanga: traditional living room for children)

The Expert System final layout will take the form of a query, **as shown in Figure 4** (b), in which the user can be an active participant in the decision of his own oriented housing profile. In order to facilitate the understanding of what is being asked in the Expert System and to help the user decide, almost all the aspects or implied decisions will be illustrated trough schematas **as shown in Figure 4** (b). The expected Expert System's output will be a group of directives for the oriented housing design. Its' expected result does not intend to reach the final design of the house and it does not intend to contribute with possible housing models because those models could later be at risk of being applied as standard models and spread without respecting the ideal of housing that responds to particular activities or particular latent aspects of those activities. It is intended, though, to help people choose among a vast group of possibilities, based on rigorous studies, and to orient them in a more sustainable construction of their house. It is made for a context of architect's absence and where the house planning procedures do not include a prevailing housing design. If one of this Expert System's outputs would be floor layouts or other technical drawings, these wouldn't, most probably, be used by the common inhabitant (he wouldn't know how). Plus, one fact supporting the feasibility of this proposal is the one of the existence of a close collaboration between the administrative housing office and the local population; almost every one desiring to build a house, goes first to the local administration to ask for a land plot. Unfortunately this relation stops here, most of the time, and the inhabitant builds the house without regard to any constructive or architectural rules. Nonetheless, the existing dialog suggests that a computer tool to be used by the poorest housing area's residents wanting to build a house would be of easy implementation at the local administrative habitat's office (since the majority of the concerning population do not have access to a personal computer).

CONCLUSION

More than a tool, the Expert System is expected to constitute a method which allows translating the environment behavioural studies concept from Amos Rapoport into direct applicable solutions for a culturally oriented housing design combining it furthermore with bioclimatic considerations. It intends therefore to constitute an alternative in the development of better living conditions in contexts of poor housing conditions, such as the ones of Ondjiva, through the application of a multidisciplinary approach. The Expert System will allow a more culturally and bioclimatic oriented self-construction and will bring new possibilities for the housing policy development, either among government institutions, NGO's or inhabitants. Therefore, the meaning of this research is in its contribution with solutions that may deliver in the future, better or more appropriate housing in slum contexts, where the self build houses lacks mainly of an oriented guiding and supervision.

ACKNOWLEDGMENTS

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Sustainability and the Urban Planning Context: Housing Development in Algeria

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ABSTRACT

This paper describes research into the development of housing in Algeria. It focuses on the history of traditional dwellings and the importance of outdoor space located inside the building: typically in the form of a courtyard. Courtyard dwellings in the city of Constantine are examined in some detail. The rapid urbanisation process taking place in Algeria in recent years together with difficulties in the planning system since colonial times has caused difficulties in responding to housing needs. The concentration of the population in smaller areas of cities has led to the need for more compact yet comfortable dwellings. The paper describes how the situation might be dealt with in the township of Jijel. A number of stakeholders are being consulted and the key results of in-depth interviews with architects are reported. The findings from the review of the existing housing areas and survey are then interpreted to make suggestions for development in the future.

Keywords: housing, urban, courtyards, design, Algeria

1. INTRODUCTION

Algeria has experienced a number of invasions and colonisations through history and this has brought new peoples and new cultures to the area with consequently new commercial and demographic inputs. These have combined with the already rich variation created by climatic regions and traditional cultures to produce a wide variety of traditional dwelling form.

In modern interpretations of architectural history, traditional architecture is often considered to be an expression of sustainability as previous generations were forced by circumstance, to build in harmony with nature and climate. Further the products were matched to cultural and social values in a much more linked way than generally occurs in the present day (Makani and Talebi, 2011). As a result traditional settlements are often considered a source of sustainable design principles because they were built using locally available materials, and with respect to thermal comfort and cultural needs of the local community (Bouchair and Dupagne, 2003).

An interesting facet of many traditional housing designs was the attempt to have some kind of outdoor space indoors; the most successful exemplar of which is the courtyard house. Courtyard houses can have many beneficial attributes – in cultural terms and also in providing the means to reduce discomfort associated with climate.

In modern dwellings there is often an attempt to bring together elements of tradition together with modern needs and also to match to the needs or urbanisation. In rapid urbanisation it is frequently the need to produce smaller and more densely packed accommodation and in such circumstances the ability to create any kind of courtyard environment is severely limited. One way of creating some kind of

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outdoor-indoor space is through the provision of individual balconies. Balconies can be left open or can be enclosed.

This paper consists of three main components: firstly examples of traditionally designed dwellings which have been researched are described and evaluated; secondly particular examples of the courtyard house are examined in more detail; and thirdly, the attitudes of architects to sustainability and the ability of current urban and housing design policies to meet needs is reported following interviews.

2. TRADITIONAL DWELLING TYPES

Examples of older style traditional houses in Algeria according to Benmatti (1982) can often be divided into three categories: courtyard houses in the towns of north of the country which can be seen in the medina of Constantine for example; housing to be found in the rural and semi-urban areas of the North (this form of housing is less homogeneous than the first category and includes the example of Kabylia); and a third category associated with housing settlements in the South; examples being M'zab, Souf and Hoggar.

It is interesting to note in the following descriptions how the old styles of dwelling accommodated social and cultural needs whilst also dealing with the excesses of the climate. Some dwellings had only private interior space; some had both private and more public interior space; and in some cases the means of achieving all requirements was the use of a courtyard.

2.1 The Kabylia House

The Kabylia Berber villages are situated in the summit, slopes of mountains or in high plateaus where a dense population live from land exploitation. Topography and climate are the factors that determine spatial structure of the village, streets and alleys which follow the geographic configuration of the site. The urban fabric is often constrained by a circular road around the summits of hills, and the houses or 'Axxam' are organised along radiants or alleys that are perpendicular to the circular road. The dwellings are often grouped and link to each other to form a larger family house.

The family house shelters the whole extended family, with the overall dwelling extended by the construction of new houses sometimes in the courtyards of the parent's house. In these traditional forms where space is not limited in the same way as in modern development, two or three generations may live together and form a sub-quarter (Toubal and Dahli, 2009).

In such rudimentary houses the family, its animals, its furniture, artifacts, equipment and products all come together (Maunier, 1926). Humans and animals are juxtaposed with minimal vertical or horizontal separation. The dwelling typically had three different spaces: a high living room for people with a fireplace, a low stable area for animals and water storage, and a shed for faring equipment and crops. The rooms are used by both male and female as the men typically spend the whole day outside working on the land and only come to the house to eat and sleep. The relationship between public and private space is not well determined in the plan as the house is effectively considered as a private place.

In Kabylia houses, high humidities can be found in spaces and activities related to water such as the kitchen and bathrooms. The Brasier or 'Kanun' occupied the driest places (Loeckx, 1998). The courtyard in the kabylia house is located exterior to the house where traditional summer activities such as pottery making are performed.

The house has a rectangular from and the dimensions are typically: exterior 7 to 7.5m length and approximately 5m wide with wall-height of about 3.5m walls. The dimension can vary depending on the needs of families and the wealth or otherwise of the household. The external walls of dwellings are thick and are normally constructed without windows and thus permit protection of the interior house from cold in winter and heat in summer; the only opening is the door. The walls are constructed from local stone and the roofs have two slopes and generally use roman tiles or clay. The structural frame is based on wooden Ash beams and olive branches, and is supported by its low side walls (Maunier, 1926).

2.2 Soufi House

The traditional houses of Oued Souf are known as Soufi Houses. The Soufis or the inhabitants of Oued Souf were originally from Yemen; looking for water and better climatic living conditions, they crossed Egypt and Tunisia to settle in Oued Souf a city in the Algerian Sahara which borders Tunisia and Libya. The city is 620 km southeast of the capital Algiers. The city is located within the Oriental Grand

Erg (Great East Sand Sea).

Oued Souf is known as the ‘city of a thousand and one domes’ for its particular architecture characterised by the uniformity of styles using cupolas, domes and vaults. The old city is situated in the city centre and surrounded by three main roads, which separate the traditional urban fabric from the new town. The old city also exhibits a traditional architecture showing a compact urban structure which is characterised by a dense network of narrow twisting alleys, different in width and direction providing shaded movement between neighbourhoods (Bourbia and Awbi, 2004).

The houses are arranged around a central courtyard covered by palms branches. They are constructed by using locally available materials particularly the desert rose, stones and plaster. The original traditional dwelling of Oued Souf is called Haouch and designated to house extended families. The house is surrounded by its external thick windowless walls and attached to three other houses in order to provide a minimum exposure to solar radiation. The walls are constructed making use of local materials such as ‘gypse’ which helps to ameliorate thermal discomfort in summer by absorbing the heat during the day and releasing it at night. Also, as sand does not store much heat due to the air between its particles. It cools down quickly after sunset and may even generate morning fog in desert conditions.

The thermal performance of ‘isothermal’ flat roofs can be improved by adding thick layers of earth. In the case when the roof is a dome (the area of a half sphere is three times that of a flat terrace), it will receive relatively much less solar radiation. Therefore, it warms more slowly than a flat terrace (Fezzai et al, 2012).

The traditional house of Oued Souf comprises a semi-public transitional space ‘skiffa’ which provides privacy for the courtyard from external strangers. The skiffa is often endowed by ‘khamsa’: a traditional way to protect the house from bad-eyes of other people. The doorstep/doorway signifies the separation between the indoors and outdoors. Also, the house includes a kitchen, a cellar or ‘khabia’ and a number of rooms ‘ghorfa’ or ‘ damsa’; if the ceiling has a form of a vault, the rooms will gradually grouped together in order to satisfy the increased needs of the households.

In the North and South parts of the house, two covered spaces called ‘sabat’ open onto the courtyard. The North Sabat permits a maximum exposition to solar radiations in winter while the South Sabat and an excavated underground area provide the protection from heat in hot seasons (Nabila, 2007).

2.3 Hoggar Dwelling

The Touareg are the people who live in Hoggar; their origin is a mixture of Sudanese, Berber and Arabic. The Touareg are a group of tribes who live in the high mountains of Hoggar in the extreme south of the Algerian Sahara (Benmatti, 1982). The region of Hoggar is the highest land region in the Sahara where many summits exceed 2500m. Despite the southerly location, the region is relatively favoured in terms of climate, and in comparison to other parts of the desert it is less hot and experiences higher rainfall.

The Touareg live in tents or in small buildings called ‘zeriba’. The tents are relatively primitive and consist of a wide leather velum envelope formed by assembling tanned goat or sheep skins painted in red and sewn together. This roof is supported by a tall wooden column in the centre and generally three other columns shorter than the first: one in the middle of the open side of the tent, the two others in the two extremities from that point. Despite its primitive form, the tent can be closed at night almost completely which can protect the inhabitants from the cold nights of winter. One half of the tent is reserved for male use (storage of clothes, saddle and weapons); the other part is occupied by the woman (clothes, personal items, and kitchenware); however the two parts of the tent are not separated by any physical barrier (Demoulin, 1928).

The Zeriba is a small hut representing an intermediate stage between the nomads’ tent and more modern forms of house. It is made of stones and covered by palm leaves. The zeriba has generally a cubic form approximately 2.5 m square in plan but sometimes with a conical roof (Pandolfi, 1994).

2.4 Traditional Courtyard Houses

Courtyard housing is a universal type of habitat and it is not unique to the Arab world or to Algeria. It is widespread in diverse regions in different geographical locations, climates, societies and cultures: several civilisations have used it as the main design component of housing such as the Assyrians, Persians, Greeks, Romans, Byzantines and more recently found in Islamic architecture. However, although courtyard housing was a key feature of traditional design in many parts of the world, there are significant differences of function and importance relating to the function of the interior courtyard in the Islamic region.

The importance of courtyards has increased under the influence of the Islamic religion and subsequently Arabic architecture took this to form a specific room/space characteristic in plan, in form and in decoration. In this, the courtyard became one of the main architectural features of Arabic houses and gave opportunity to develop a variety of associated features: loggias, galleries, high level openings, oriels and elaborate sun-shade ornamentation (Edwards et al, 2004).

The study will focus on the medina of Constantine as one of the oldest medinas in Algeria and in which fine examples of traditional forms of Courtyard Houses are to be found.

3. THE MEDINA OF CONSTANTINE

Constantine is one of the oldest cities of Algeria which dates from 3000 BC. It is situated in the centre of the North East of the country. The city was a base of the Phoenicians, Romans, Vandals, Arabs, Ottomans and finally the French. The medina of Constantine is classified as of national heritage significance. The urban fabric of the medina is extremely dense and the network of streets and routes in the medina follows directly the morphology of the site. Unlike the streets and boulevards of occidental countries, the layout of roads has an organic plan and has no regular geometric form.

An analysis of the plan of the medina shows that the urban fabric has two different urban forms: a central area of souks (markets) which is exclusively related to commerce and culture; and a private residential area. The division of these areas is explained by the principle of separation between public (commercial) and private (residential) zones.

The traditional quarter of Souika is situated in the South East of the Medina. It still retains the major part of its original urban structure. The plan of Souika is composed of a homogenous irregular urban fabric. The residential clusters form small neighbourhood units within which basic neighbourhood facilities were provided such as a bakery, public baths, mosque and a school. The clusters are formed by a maze of roads with a spatial hierarchy from winding alleyways ending by cul-de-sac which maintain the public/private relationship and separation.

Streets in residential areas are either partially covered by cantilevered volumes *sabat* or totally by additional living spaces. Overall the hierarchy of streets is as follows:

1. A commercial axis as a public street.
2. Secondary roads as semi-public streets.
3. Alleyways and small streets/cul-de-sacs as private roads.

The difference between the main commercial axis and the private cul-de-sacs is one of the important characteristics of the residential urban fabric of the Arab-Islamic medina. This variation allows the separation between the private domain of housing and the public areas in order to provide privacy of houses on the urban scale. See figure 1 for an image of a typical house in Constantine.

Figure 1 Traditional house in the City of Constantine, Algeria

4. SPATIAL ORGANISATION OF THE COURTYARD HOUSE

Traditional houses in the medina of Constantine have a simple irregular geometric form consisting of two or three-storey structures surrounded by external windowless walls and organised around the courtyard. The houses are in most cases provided with pitched roofs inclined to the patio/courtyard area. The plans of the houses are generally similar in their basic characteristics but may vary in detail, and spatial organisation and the hierarchy of spaces in the houses are very similar.

Courtyard houses of Constantine are generally found in three forms:

- Houses with columns and arches which indicate occupancy by more affluent families.
- House with large pillars, columns and lintels, which represent the more generally found dwellings occupied by intermediate households.
- The third form is similar to the second but is differentiated by the elevation of its patio from the floor to allow the use of the ground floor as a store area. This type of house is generally located in more commercial street areas.

Generally however there is no social or spatial segregation between poor and rich families and both live side by side with each other, the only signs of difference being the height of the house and the decoration of the external doors. In all cases the courtyard receives and distributes sunlight and fresh air to the other parts of the house.

The courtyard also serves as the focus for the preparation of food, and as a laundry, children's play and outdoor living space. It also acts as a circulation space surrounded by alleyways and arched galleries which are designed to avoid any direct visual intrusion (from the semi public spaces into the private central space of the house). Further it provides a covered transitional space between the rooms and the open part of the court.

The courtyards of vernacular dwellings in Constantine have a regular form: square or rectangular. Their length is varies between 8-10m, whilst their depth is between 2-3m, possibly because of the limit of available cross-beam length.

Figure 2 Typical layout of a courtyard house in the City of Constantine, Algeria (ground floor left, first floor right) Key: 1 = Public (Bit, skiffa); 2 = Semi public (Services); 3 = Private (Female and family living, or bedroom; 4 = Open space (Courtyard); 5 = Transitional spaces (Riwak).

The rooms generally located at its two extremities are elevated doukana (storage places). The central area of the room (Kbu) is opposite to the door and is balanced by two lateral sitting bay areas. The house is accessed through the skiffa, a small angled space which connects the public (exterior), semi-public and private spaces of the house (Barkat, 2006). The skiffa is also the reception area for visitors, particularly men who are not allowed to enter into the house. This place is connected directly to a reception room which is the most decorated room in the house and designated to receive male guests. Figure 2 shows the generalised form of the courtyard house set on two storeys.

5. THE PROVINCE AND CITY OF JIJEL

The Province of Jijel is located in the north east of Algeria and until 1974 it was a sub-prefecture of the Province of Constantine. It is bordered by the Mediterranean Sea to the North with a coastline of 120 kilometres, and the Provinces of Skikda in the East, Bejaia in the West, and of Setif and Mila in the South. It is divided into 28 communes and 18 sub-prefectures (Dairas) and has a total area of approximately 2400 km^2 of which 82% is mountains; it has an estimated population of 650,000, most of whom live in the North part of the Province. The actual City of Jijel has an estimated population of 134,000 inhabitants and occupies just 62 km^2 (2.6%) of the land area of the province, and this results on a high density of population of 2,140/km^2 (when the average density is just 264 persons/km^2 (Wilaya de Jijel, 2013).

Due to its strategic location, Jijel has been an attractive destination for colonists since the pre-Roman times. The city was prosperous in Phoenician, Carthaginian, Roman, Byzantine, and Arabic times. Following a large earthquake in 1856, the reconstruction of the city took place under the French occupation resulting in a new city designed by Scheslat in 1861. The city was built in an orthogonal plan focused around the military garrison 'the citadel'. The plan was similar to European cities with a triangular form constrained by the terrain form and also by the layout of ramparts, the rules of fortification, and the location of the gates into the city. According to the principles of Haussmann's urbanism, this plan included the key elements of urban fabric: the regularity of pathways, the alignment of the road structure, and the important role of public areas and squares.

The distribution of the population of showed a concentration of colonists in the North part of the triangle, close to the citadel, the Sea and around the already existing facilities. The native population was grouped in the South West part of the city and occupied a very dense area with very tight access from narrow streets. In 1885, the port was rebuilt and later the Eastern area became an expansion area for the colonists who built housing developments with beautiful villas facing the beach. On the local Arab side, informal settlements spread parallel and outside the triangle and created two new quarters: la Pepeniere and the Faubourg (Safrai, 2008).

After Algerian independence, Jijel witnessed an increase in population arising from a rural exodus towards the city. However, no spatial expansion was planned and little organized construction took place. This resulted in the densification of indigenous quarters and the appearance of other new spontaneous quarters: village Mustapha, la Crete, etc.

From 1974, with the nomination of Jijel to the status of provincial town and the implementation of a special development programme, there has been a considerable rise of population (the population has multiplied by 3 times in a period of 20 years, from between 1977 and 1998.

6. HOUSING POLICY AND HOUSING DEVELOPMENT IN JIJEL

Since the 1970s there has been a very sharp increase in demand for housing, particularly social housing. In this period the city initially grew haphazardly by juxtaposition of urban entities in particular informal housing. The urbanisation of the city occurred rapidly and without much detailed forward thinking on urban development in both medium and longer terms. This has impacted on the fragile balance between the urban system inherited from the colonial period and created morphological and functional failures that make urban management rather complex (Safrai, 2008).

From 1985, the increasing housing crisis and the emergence of informal settlements lead to the launch of a major public housing program and the creation of three new zones of urban habitat 'Zone d'Habitat Urbaine Nouvelle', each of which have been designed to accommodate 50,000 inhabitants (Hallal, 2007). These Zones were well intentioned; however their implementation has been less satisfactory because of the emergence of informal settlements. This situation was aggravated particularly in the period between 1990-2000 due to the civil war, the resulting insecurity, and the degradation of living conditions in rural villages and mountains. Urban and architectural decisions in Algeria and particularly in Jijel have sometimes been made according to political and personal evaluations which are sometimes more powerful than urban planning instruments, and this can have significant adverse impacts.

One of the key design features which is seen in the high density development to meet urgent social needs in Jijel has been the lack of development with regard to traditional design. This has led to multi-storey apartment blocks which have forms of outdoor-indoor spaces – balconies etc, but without the attributes understood and liked by the indigenous population, see for example Figure 3.

Figure 3: Example of ‘closed’ balconies

7. SURVEY OF BUILDING PROFESSIONALS

The research project, of which this paper reports a part, is involved in integrating the views of stakeholders into the design and construction process in a much more influential way. However in order to do this, existing knowledge and attitudes must be known. A number of detailed interviews have been carried out with stakeholders, and the results of the first phase of these, with an influential group of architects and other professionals is reported here.

The study was carried out with twenty-one architects and engineers working in either private bureau or public administrations. The aim of this questionnaire was to assess the knowledge of architects in Algeria in terms of sustainability which can affect the quality of design and the sustainability of the built environment. It also sought views and understanding on differences between traditional and modern design of dwellings.

- On the question concerning sustainable development objectives: 16 professionals answered that they have an idea of the objectives and on what makes a building sustainable; however, only 3 out of 21 gave a suitably detailed definition and the others just related the subject to energy consumption. In addition, 17 out of 21 think that the Algerian Government is not making sufficient effort to raise awareness amongst public and professionals on the topic of sustainability.
- In relation to comparisons between modern apartments and traditional courtyard houses in terms of sustainability, 14 respondents out of 21 preferred the traditional house and they argued that the traditional design respected the lifestyle of local inhabitants. Also, they stated that the courtyard provides more natural light and better ventilation to the dwelling.
- A majority of interviewees (14 out of 21) also agreed that traditional architecture satisfied the needs of the local population in terms of space, while only 7 out of 21 thought that modern design and construction met the needs of the inhabitants. 13 out of 21 interviewees claimed that traditional design met the needs of local population in terms of comfort. However, only 4 out 21 agreed that traditional design respected urban level regulations in Algeria. Some of the interviewees think that is because the regulations were only devised some time after traditional design had evolved.
- All the interviewees agreed that it was important to consider the opinion of future inhabitants in the design of new houses.
- It was clear that the majority of professionals do not have sufficient understanding of the subject of sustainable development which affects the quality of the built environment.
- The vast majority (20 out of 21) of the architects interviewed thought that the quality and impact of urbanism and the built environment in Algeria is poor and lacks respect of regulations.

- Some of the interviewees suggested that the design of future housing projects should fulfill the ‘real needs’ of households. They also believed that future design should consider the climatic and environmental factors of the region. Moreover, they thought that the Algerian government should improve the quality of construction in terms of space, comfort and aesthetics.

8. CONCLUSIONS

Vernacular houses in Algeria have varied according to different climatic and geographical regions. Houses design, the use of local building materials and construction system were adopted for each region separately in order to cope with different environmental factors and resource availability. Thus each type fulfilled social needs and society values and traditions in different ways.

However, it is not possible simply to use the systems and practices from previous generations but there is need to study and learn from their experiences and the sustainable systems they introduced (Eiraji and Nambar, 2011) but also to adapt. Human behaviour and culture should also be considered in modern housing design (Vaziritabar, 1990) and future cities should be created by learning from historic and traditional cities: conserving cultural heritage and promoting sustainable development in order to suit contemporary needs.

Urban policies which lead to new housing development need to take into account the older traditional forms but in new ways such as to introduce new forms that can replace the older courtyard form seen so successfully used in Constantine. New housing must also be sustainable and therefore new policies and actions must be informed by current stakeholder views but also seek to address and modify those stakeholders’ opinions. The results of the interviews indicate areas which require attention and can be developed for more sophisticated analysis. This research ultimately aims to combine sustainability potential in traditional architecture with modern technologies and occupant needs to create new sustainable cities that suit present and future needs of the inhabitants.

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Expographic Lighting in Reused buildings, a Preliminary Assessment of Three Museums in Algiers

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ABSTRACT

The city of Algiers comprises eight museums, more than half of them are reused buildings. In this paper, we are interested in the museographic lighting requirements in reused buildings that haven't been initially designed for expographic purpose. The conversion of buildings into museums may have some constraints. Natural light is an important constraint whose modeling depends on formal, structural and spatial characteristics of the building. And supplying with artificial lighting depends largely on it, thereby having direct repercussions on energy consumption. Conversion of historic buildings, in itself exhibition subjects, can also reduce adaptive space possibilities to museographic lighting requirements. This paper is the synthesis of a master preliminary study where we attempt to assess the exhibition's lighting quality in three reused buildings, based on blueprints (metric supports), the author's observation and photographic supports. This preliminary assessment is aimed to evaluate the case studies through literature recommendations of "accent" and "ambient" lightings in exhibition spaces. Despite the constraints related to the conversion of a building into a museum and the importance of lighting design in expographic quality, it may be possible to ensure a lighting quality by adapting the collection types to the space opportunities especially related to natural light. The heavy architectural structures present more constraints than light architectural structures, limiting exposition to permanent collections, especially 3D artworks with consequent dimensions that are the best recommended with natural lateral lighting. Oppositely, the light architectural structures induce flexible and big spaces that seem to be the best adapted to temporary collections especially when offering natural zenithal lighting for "ambient" requirements.

INTRODUCTION

Exhibitions, representing places of themes, interaction, communication and entertainment, are available in a wide range of types, varying according to the theme, content, temporality, scenography and the space housing the exhibition. Museums, being the warehouse of our tangible cultural heritage, represent the largest exhibition venues [1]. Museum culture in Algiers tends to be developed through various activities that take place in the institutions of the capital, and whose number is increasing. This has in part led to the conversion of a number of buildings into museums to host this kind of cultural events. The quality of a museum exhibition is conditioned by a number of requirements related to visitors comfort, artworks conservation, and to the exhibition space itself. It is through these requirements that "lighting" is raised as a predominant factor [2]. In this work, the interest is focused on expographic lighting, especially on two of its components, which are "ambient" and "accent" lighting. The third being the "orientation" lighting that has a very little influence on modeling space and appearance of the exhibited artworks. The expographic lighting is provided by the combination of natural and artificial lighting that depends on some parameters: temporality (with exhibits that may be permanent or temporary), the type of collections on display (2D or 3D objects), and the space housing the exhibition. If the natural lighting is yet a challenge that has to be met in the first phases of the design process, because its management and modeling depend entirely on the formal, structural and spatial characteristics of the building~~,~~ that influence the distribution of illuminance, luminance ratios, and the perception of light, what to say about the building converted to host a museal exhibition~~,~~ that involves considerable constraints, inducing an important supply of artificial lighting with considerable energy consumption [3, 4]. In this paper, we attempt to raise the qualitative aspect of museum lighting through some recommendations issued from a preliminary assessment of three case studies. These recommendations could help the architect to integrate lighting feature in upstream of his reflection in the design of a museum or conversion of a building into a museum.

MUSEOGRAPHIC LIGHTING REQUIREMENTS

Combined lighting

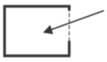
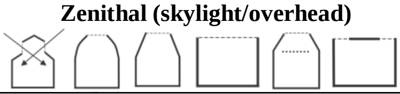
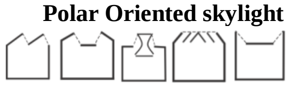
The perception of the exhibition, the visitor intuitive orientation and quality of environments are a central concern in a museum space. A suitable level of lighting must meet the requirements of the conservation works and facilitate the adaptation of visitors to the area, while distinguishing each space from another, etc [5]. The museum lighting is defined as an underlying factor in exhibition quality, and is declined in different types, but the focus in this paper is on its role of expression element through expographic lighting, as “ambient”, and “accent” lighting. “Accent” lighting helps to highlight the exhibits and the architecture, and to emphasize their various components and characteristics. This induces the creation of a hierarchy in perception, depending where attention must be captured [6, 7]. “Accent” lighting is designed for numerous purposes such as differentiating objects or artwork through various levels of illumination, or more precisely to model sculptures, etc [7, 8]. While “Ambient” lighting is generally a diffused lighting designed primarily to show the proportions in a space and the limits of a room. It provides the space a general brightness that facilitates the observation of displayed artworks, as well as showcasing the space itself [2]. So, we can admit that museum lighting is a secondary language, meeting the criteria of a semiotic system as its other elements, resulting in the interaction between space, object and visitor [9]. With all these considerations, the expographic lighting depends largely on the exhibition theme and the expected impression and emotion to provoke. Concerning the conversion of a “historic” building into a museum, the expography has to embrace the space, avoiding any additional structure that might affect the building itself as an authentic “heritage”. Its design is related to the exhibition temporality, the exhibits type (2D or 3D) and the existing natural lighting devices~~.~~

Natural lighting

Advances in artificial lighting tend to reduce the importance of natural lighting in architecture, and so in the exhibition spaces. But improving the architectural experience, ensuring greater satisfaction through the artwork appreciation, connecting the visitor with the outside, ensuring a positive psychological impact, and reducing the energy consumption; are all_reasons that encourage the integration of natural light in exhibition spaces [3, 10, 11, 12, 13]. Natural light is assured by different device typologies~~,~~ with various characteristics and effects, such as lateral lighting device, zenithal lighting device and polar oriented skylight [8]. Concerning the “ambient” expographic light, configuration and characteristics of the space play an important role, because the space’s height and surface, the proportions of openings, and so on, determine its ambience. Soft diffused light is generally considered as a leading “ambient” lighting element. For the “accent” lighting, zenithal and polar oriented devices are the most recommended for lighting two-dimensional subjects (2D) and present the best compromise for daylighting a flexible space hosting temporary exhibitions, preventing direct sunlight from penetration and overcoming the reflection that causes glare~~s~~. While the lateral lighting device is the most constraining for 2D artworks and particularly for temporary exhibitions, it is better suited to permanent exhibitions composed of 3D objects due to the shading patterns generated by the luminous flux.

In the following table are summarized the literature recommendations about expographic natural lighting devices that we classified into four ascendant degrees of quality: “less recommended”, “just recommended”, “well recommended” and “highly recommended”. [Tab.1]

Table 1. Natural expographic lighting recommendations

		Natural lighting		
		Lateral 	**Zenithal (skylight/overhead)** 	**Polar Oriented skylight** 
Ambient		Just Recommended	Highly Recommended	Well Recommended
Accent	**2D**	Less Rec.	Just Rec.	Highly Rec.
	3D	Highly Rec.	Well Rec.	Well Rec.

Rec. = Recommanded

The openings type plays an important role in the exploitation of exhibition space; so it is recommended to optimize the exhibition surface by minimizing the openings surface. A well-designed natural lighting strategy could direct visual accent to the display without glare surface at modest levels of lighting. In this context, the electrical lighting loads can be reduced and compensated by the natural light, instead of an increase in competition with excess of clarity [8]. The objectives of natural lighting exploitation in the exhibition spaces consist~~s~~ in maximizing the light source by using its features and eliminating its defects and drawbacks. This is done by considering parameters and requirements related to the space, the exhibits sensitivity, as well as the visitors’ comfort [9, 11]. And so, natural lighting should be considered before each exhibition program for both conservation and exhibition requirements. Its expertise generally supported by detailed graphics on devices and openings, should be perfected by an experimental computer modeling showing the lighting comportment [2, 11].

Artificial lighting

Unlike natural lighting, the peculiarities of artificial lighting are precision in controlling the direction and amount of light used, as well as the constancy (regularity) [8]. The exhibition spaces are therefore not subject to seasonal or diurnal variations, contrary to natural light, but characterized by stability and adapted control, more suitable to the standards of artworks conservation. For the temporary exhibitions characterized by a short time visit in a museum, the flexible lighting is the most recommended, which only the artificial lighting could offer, through focused rail systems~~,~~ rotary and swivel spots, etc. [4]. Artificial source typologies are classified according to their distribution of light, and there are three main types. Firstly, the “direct light” which can be diffused, focused or framed. The “direct diffused light” gives the background a significant importance by uniting it to the exhibit, while a “direct focused lighting” narrows it. “The direct framed lighting” decontextualizes subjects through the contrast it creates~~,~~ and therefore allows the reduction of the illumination. Secondly, the “Indirect lighting” and finally the “direct/indirect lighting”. [4]. [Tab. 2]

Table 2. Artifical expographic lighting recommendations

		Artificial lighting				
		Direct				
		Diffused 	**Focused** 	**Framed** 	**Indirect** 	**Direct/ Indirect**
Ambient		Highly Rec.	Well Rec.[1]/ Less Rec.[2]	Highly Rec.[1]	Highly Rec.	Highly Rec.
Accent	**2D**	Just Rec.	Highly Rec.	Highly Rec.	Less Rec.	Just rec
	3D	Less Rec.	Highly Rec.	Highly Rec.	Less Rec.	Just Rec

Rec. = Recommanded / [1] For dramatic ambiences / [2] For soft ambiences

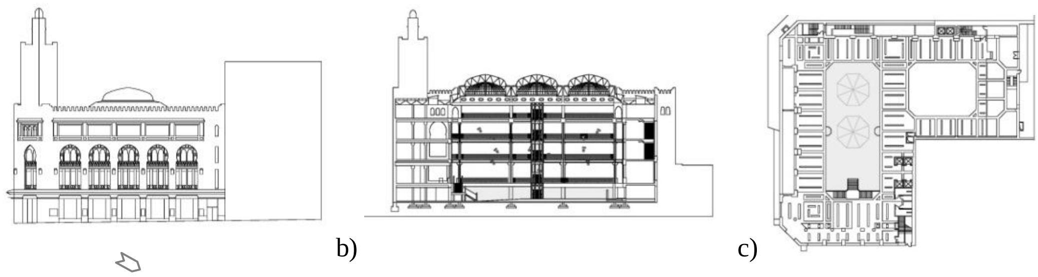
One of the main concerns of artificial lighting is energy consumption. Each project must have accurate energy balance and where possible, a comparison with the previous installation. In addition to this assessment, it is recommended to use low-consumption lamps, such as LED or compact fluorescent lamps [14]. The use of motion sensor or timer which could improve the conditions of artworks conservation is also recommended for energy economy [14]. In theoretical view, natural light should be considered as the main source of expographic lighting and artificial lighting should be considered as a complement, to bear deficits or to meet the conditions of conservation works. Even if all the criteria cited above, are difficult to combine in a museum, they must be carefully stated and considered for best expographic lighting quality [2].

METHODOLOGY

Case studies

The Museum of Modern Art of Algiers

The museum of modern and contemporary art in Algiers, called MAMA (Musée d'Art Moderne d'Alger), was inaugurated in 2008. It is the first major commercial structure devoted to the cultural sector and the first conversion operation of an old colonial monument of such importance (Fig. 1a). The museum is currently entirely devoted to temporary exhibitions and hosts 2D and 3D artworks. The building is constructed on five floors, including a basement arranged as a Central Exhibition space (atrium) and the exhibition galleries are arranged around the atrium on the different floors (Fig. 1b,c). With a natural light structure, it has three glassed domes, surrounded by small skylights, shaped like stars (Fig. 1c). A staircase initially centered in the atrium has been removed during the building conversion to offer the museum more flexibility in terms of planning.

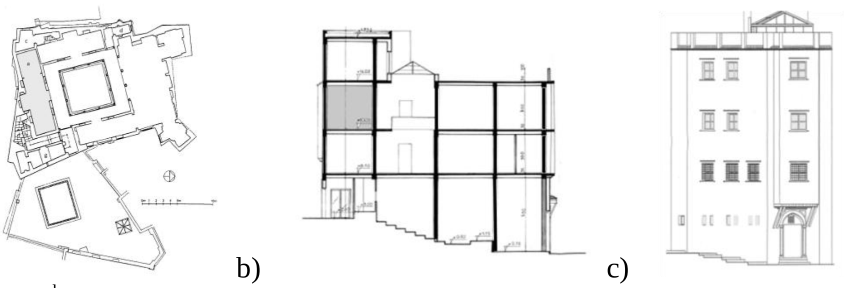


a) b) c)

Figure 1: (a) Elevation (b) Section (c) 1st floor plan.

The national Museum of Folk Arts and Traditions

The historic Palace where are kept the ethnographic collections of the Museum of Arts and Popular Traditions was built in 1570 by the Ottomans. Located in the old city, it became a museum of popular arts and traditions in 1961 after the acquisition of a permanent collection that includes around two-thousand objects related to crafts and other popular arts, which are predominantly three-dimensional. The museum itself is an exhibit, regarding the importance of its history and architecture. The exhibition entity consists of four levels with floors built around a patio and equipped with lateral openings (Fig.2 a, b, c). The whole building occupies an area of 595 sqm, and has been constructed by a rigid structure with masonry walls. The museum hosts its permanent exhibition, as well as temporary or itinerary ones.



a) b) c)

Figure 2: (a) 2nd foor plan (b) Section (c) Elevation.

The National Museum of Antiquities

The National Museum of Antiquities is the oldest museum in Algeria and Africa, inaugurated in 1896. After several displacements of the collections, the conversion of the first normal school of teachers into a museum permitted to fix these collections. The museum currently hosts historical and archeological pieces reflecting the history of Algeria and the Maghreb for two thousand years, with a collection of sculptures, ceramics, lamps, Roman pottery… which are mostly three-dimensional objects, through permanent and temporary exhibitions. The building, with a rigid structure of masonry walls, has several spaces distributed in the ground floor and arranged around a courtyard (Fig.3 a, b). It has side openings with a skylight in the dome (temporary exhibitions space) (fig.3 c).

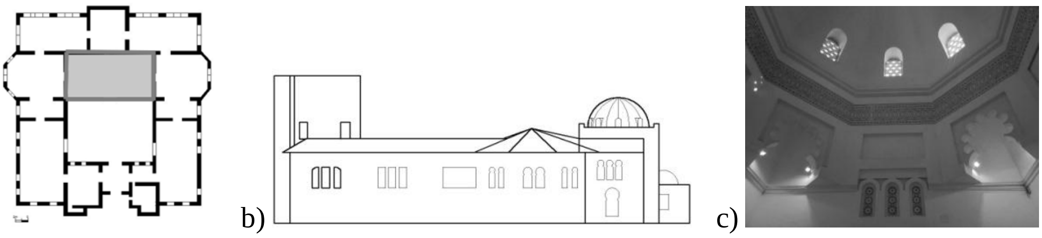


Figure 3: (a) Ground floor (b) Elevation (c) Temporary exhibitions space.

Method

This study was conducted in two major phases: the first based on a literature review of exhibition types, requirements and conditions of expographic lighting quality. Through this literature review, we tried to synthesize the recommendations of the expographic lighting, combining natural and artificial lighting, in terms of "ambient" and "accent" lighting (for 2D and 3D objects). These recommendations have been formulated as a reference tool used in the following phase. The second phase concerned the assessment of expographic lighting quality in three reused museums with the recommendations' filter. This assessment is essentially based on observation, graphic and photographic supports collected by the author.

RESULTS

The following table summarizes, from literature review, the recommendations related to the choice of lighting type, whether natural or artificial, depending on expographic requirements for "ambient" and "accent" lighting.

Table 3. Assessment of natural and artificial expographic lighting in the case studies

		Natural			Artificial				
		Lateral	Zenithal	Polar Oriented	Direct			Indirect	Direct/ Indirect
					Diffused	Focused	Framed		
Ambient		Just Recom mended	Highly Rec.	Well Rec.	Highly Rec.	Well Rec. [1] Less Rec. [2]	Highly Rec. [1]	Highly Rec.	Highly Rec.
Accent	2D	Less Rec.	Jut Rec.	Highly Rec.	Just Rec.	Highly Rec.	Highly Rec.	Less Rec.	Just Rec.
	3D	Highly Rec.	Well Rec.	Well Rec.	Less Rec.	Highly Rec.	Highly Rec.	Less Rec.	Just Rec.

Rec. = Recommanded / [1]For dramatic ambiences / [2] For soft ambiences

Museum of arts and Traditions — Museum of Modern art — Museum of Antiquities

Case 1: The Museum Of Modern Art of Algiers

The “Museum of Modern Art” hosting temporary exhibitions has a number of advantages in term of “expographic” lighting such as overhead natural lighting devices, which theoretically represent the best source recommended for temporary exhibitions. But the devices composed of three large domes and little skylights do not ensure a sufficient “ambient” lighting because of the important height of the atriums, composed of 4 floors (fig.4a). To resort to this weakness, a supplied indirect artificial lighting has been installed with fluorescent projectors oriented to the ceiling (55W/4000K/ IRC>90), direct projectors oriented to the floor (fig.4b) and indirect lighting embedded in the ceiling (indirect diffuse-batten fluorescent luminair- 54W/4000K/ IRC>90) (fig.4d). The central atrium space is then provided with a soft light uniformly distributed. Without the “accent” lighting, the paintings form a single unit with their background. Artificial light plays its substitution but also its widening work role, and meets the needs of “accent” lighting, highlighting the exhibits and offers opportunities necessary for the flexibility of a space welcoming temporary exhibitions. Through rotating spotlights on rails, that ensure the emphasis of artwork with a direct focused or framed lighting (halogen lamps 50W-3200K-IRC100) (fig.4e), it highlights the artworks that stand out from their background, to guide the look toward the artwork, an effect exacerbated by a lower “ambient” illumination (fig.4c). These devices generate a combined lighting predominantly artificial for the temporary exhibitions.

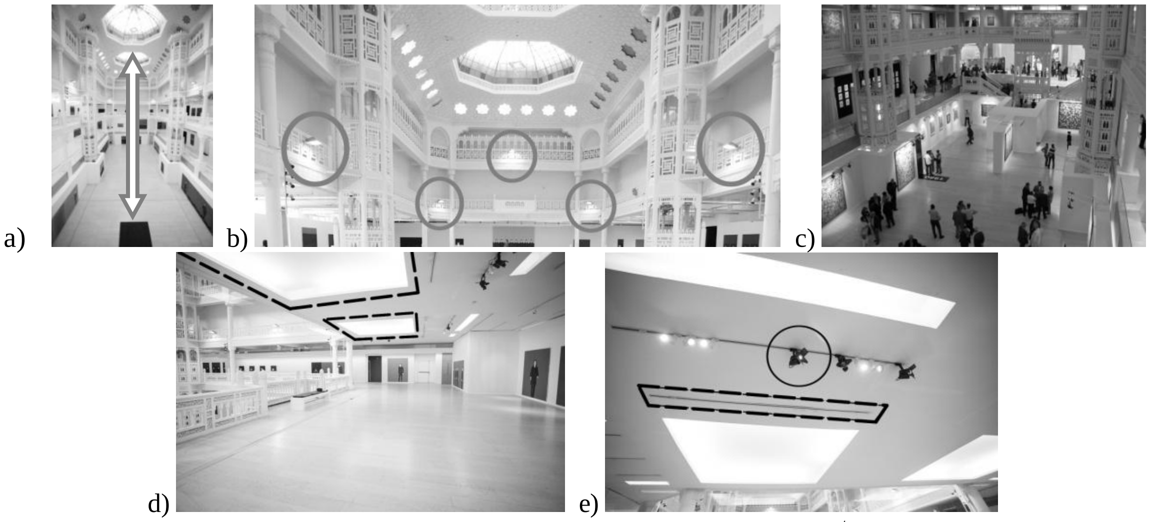


Figure 4: Interior photographies of the museum (atrium and the gallery at the 1st floor).

According to the synthesis table (tab.3), the MAMA museum should meet the "Highly recommended" device for natural lighting, but in reality, with the narrow and deep spatial form of the atrium the natural light is insufficient for “ambient” requirements and completely absent for “accent” expographic requirements. So, deficient natural lighting has been supplied by focused artificial lighting, highly recommended for 2D and 3D objects, adapted to temporary exhibitions that the museum welcomes. Although the artificial lighting ensures adequate expographic lighting, its dominance induces important consequences on the energy consumption.

Case 2: The Museum of Popular Arts and Traditions

The “ambient” lighting is provided by a diffused natural light penetrating through the entrance and windows (fig.5). The lack of artificial lighting here may be a problem when the illumination drops. The “accent” lighting here is provided by adjustable halogen spotlights (20W- 3000K-IRC>90), with direct light focused but illuminating a small area of the space and the exhibits in the showcase (fig.5). The exhibits are mostly three-dimensional and lack “accent” lighting, knowing that the diffuse daylight in this space offers little modeling, especially when the sky is cloudy.

Figure 5: Photographies of the “Algiers” exhibition hall (Permanent exhibition - 2nd floor)

The specificity of this museum lies in the fact that it is a "heritage", with heavy loadbearing walls of historical nature. In this case, the lighting of the building and its architecture is as important as objects that are exhibited. The exhibition spaces here are too small for the collections that are hosted and do not allow the visitor to move back and appreciate the exhibition. According to the table 3, the museum should meet the "highly recommended" devices for artificial lighting, but in reality, the presence of this light does not meet the quality requirements, given the number and orientation of lighting devices, that do not fit the needs in terms of expographic lighting. As for the natural lighting, the only existing device is side lighting, which does not necessarily ensure the level of illumination needed for the exhibition, which would have been suitable for permanent 3D collections of small or average size only. The adaptation of the exhibition to the space should be taken into account by the designers, through the ability of the building to accommodate (structure, accessibility, strength of the frame, etc) with a light that targets the architecture of the building, as well as the exhibits.

Case 3: The National Museum of antiquities

Natural diffused light entering through the windows positioned at an important height (gaining exhibition surface) and featuring a diffusing glazing, helps illuminate the space and the objects that are on display (fig.6a). This natural source is supplied by a direct artificial light, with fluorescent tubes (58W-5250 lm-IRC>80) (fig.6b, c), which remains insufficient in case of illumination drop, given the number of devices and surface space. In this museum, the emphasis of the collection is ensured by natural lateral light which in case of high levels; significant shading patterns are generated on sculptures. In the table 3, lateral natural lighting is highly recommend, but in this case study the high proportions of the sculptures, compared to the space measurements and the windows’ disposal, led to the need of artificial light supply for “accent” requirements. This supply should enhance the exhibition quality of the artworks, but artificial “accent” lighting is only present in the showcase (direct diffused lighting).

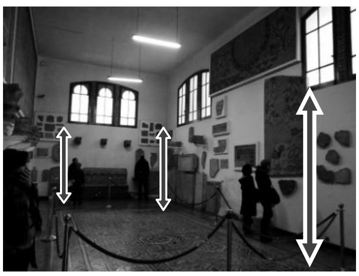
a)  b)  c) 

Figure 6: Photographies of the “Christian art” and “Marbles” exhibition halls (Permanent exhibition)

According to the synthesis table 3, the Museum meets the "highly recommended" devices for artificial lighting, but in reality this light does not answer all the quality requirements, in terms of number and type. With the lateral natural lighting, the spaces are only side-lit, which is certainly favorable for some sculptures, but in excess for high sculptures and insufficient for accentuation of small 3D objects and 2D objects. All the “accent” expographic lighting defaults should be corrected by supplying the space with artificial lighting adapted to each space and to each type of objects. In this museum, two main problems arise: the first is the abundance and numerous varieties of museal objects face to the rigidity of the spaces (fig. 6a, c) and the second is the same combined lighting devices existing in all exhibition spaces despite the big variety of the collections. For these permanent collections, improving the combined lighting according to every collection requirements will considerably enhance the expographic quality; but in our opinion, if the museum was adapted to the first collections in 1896, today this important cultural heritage deserves to be hosted in a new building museum with more flexibility and more adapted expographic lighting, specially designed for these collections.

CONCLUSION

Some converted museums offer better expographic lighting than others. Through this preliminary study, it seems clear that the conversion of a building into a museum requires an assiduous appraisal to evaluate the opportunities that the building offers. Strengths and weaknesses should be studied in accordance to numerous factors among which are the exhibition type (permanent or temporal), the collections requirements (2D, 3D, proportions), the conservation requirements and the energy consumption. From the case studies assessment, we retain that more the converted building offer flexible spaces, more it can fit the expographic lighting requirements but with heavy consequence on energy consumption when the natural lighting is insufficient. The Museum of Modern Art of Algiers seems to fit the expographic lighting requirements for temporary collections with the flexible spaces it offers, particularly the central atrium capturing the zenithal natural ambient lighting, even if insufficient. In its category as a museum of temporary exhibition, it seems to be a good example needing extensive study of its artificial lighting in order to reduce the energy consumption. In its category as a museum of permanent exhibition, the museum of Popular Arts and Traditions seems also to be a good example of collections adaptation to the space. The natural lighting is insufficient and the supplying artificial lighting should enhance both the expographic and the historical character of the building. The third museum seems to be the worst example, where spaces don’t fit either objects proportions or lighting requirements. The main recommendations we retain from this preliminary study is that in a reused building, the “natural lighting” should be the first considered and foremost factor to chose appropriate collections and to supply with adapted artificial lighting with energy consumption care.

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Deconstruction + Reuse = NØ Waste

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ABSTR ACT HEADING

How much does it cost to rehabilitate and extend, with optimal conditions of habitability, a non-used building versus starting a new one from scratch?

One of the main challenges we are facing nowadays in order to fight against climate change is the efficient use of resources in all areas of society. From the scopes of architecture and building sciences, the efficiency in the management of resources will be key for improving our capacity of adaptation towards the requirements of sustainable development and climate change. This issue is directly linked to the topic of rehabilitation versus building from scratch (starting with a new floor plan).

The research developed for the thesis "Life cycles of materials. Building from scratch versus rehabilitation and extension of the traditional dwelling from Extremadura" presents values that go far beyond the estimations made for the initial hypothesis; the impacts on the quality of the natural environment of a renewed-extended existing dwelling is 63,42% lower than the impacts generated by building a new one. Specifically in economical terms, the costs of a renewal/extension of an existing dwelling are 36,90% lower than the costs of a new building.

Having these data values, a quite important question is still in the air: Which will be the steps required to be able to acknowledge society about this issue?

We have completed an empirical demonstration in the case study of the dwelling in C/ Colón 36, in Castuera (Spain), where we present the process to obtain satisfactory results using the following methodology:

DECONSTRUCTION + REUSE = NØWASTE

INTRODUCTION

Nowadays, the habitation requirements for dwellings leave out any possibility of renewing traditional housing. Everyone wants to live in a new house, and never think about renewing an old dwelling using popular architectural technics. Although this type of dwelling was already designed with integrated passive architecture, their owners are just either waiting for its collapse or to be demolished in order to build new ones.

Throughout history, in different regions of the world, many cultures have reutilized materials from other constructions to build new dwellings, great buildings, monuments... But after the industrial revolution it is only considered to build using new materials.

We believe it's time to change this paradigm. Some architects have thought of this idea, as we have now the technology for analyzing materials and creating virtual designs before building. That way we are able to calculate if it's feasible or not, and how these materials can be reutilized in order to obtain more efficient buildings. I´ve been working and researching on processes of reutilization and on this type of architecture since 2004. We have worked with passive design, materials reuse, simulation software, Life Cycle Analysis, situated technology and local knowledge, obtaining the best design answers for the needs of its inhabitants. These technics are: DECONSTRUCTION + REUSE = NØ WASTE.

INTENT AND OBJECTIVES OF APPLIED RESEARCH

Our intention is to answer the following question: ¿How much does it costs to renew and extend, in optimal conditions of habitation, a non used building versus a new construction? When we ask "How much does it costs" it refers to economical value but also to environmental impact.

GENERAL OBJETIVE: To determine, through comparison, how much it costs to rehabilitate and to extend, in ideal conditions of habitability, a building in disuse versus a new building: environment impact and economic value.

SPECIFIC OBJETIVE, working on interventions with real projects:

1. Acquiring knowledge about construction system in dwellings from Extremadura (Spain).
2. Acquiring knowledge about construction systems in new dwellings.
3. Assess the materials and construction systems to be efficiently reutilized in dwellings renewal.

METHODOLOGY AND TOOLS

The methodology is based on the following processes: search of bibliography, search of data bases (demography, climate, materials, construction details and local technology), analyzing traditional construction systems in Extremadura and in projects of new dwellings built from scratch.

The tools used for obtaining these results are:

1. SIMAPRO (ECO-INDICATOR 99); valuation of damages in several areas of impacts:
   1. Human health: expected years of life adjusted to disabilities, used on the World Bank and in the World Health Organization. (W.H.O.).
   2. Ecosystem Quality: (m2·yr·PDF) square meters of surface of vegetal mass that will endanger some species that may potentially disappear
   3. Resources: Megajoules needed to obtain low quality minerals and fossil fuels in the future.
2. ARCHISUN: acquiring and comparing values of energetic consumption in dwellings after built.
3. Price basis of Extremadura: overview for comparing the costs in € between the following case:
   1. Unused dwellings after renewal and extension.
   2. New dwellings built from scratch.

OUTCOMES AND COMPARATIVE

In this research, we have compared two cases to be able to know the impact and economical cost in each construction unit, but also the energetic costs after finishing the construction process. The analyzed buildings had similar dimensions, but for a better comprehension and comparison, in the impact analysis we have work with built square meters. This way we managed to work with exactly the same measurement on each construction unit, as normally each material is measured in different units (concrete: m3; steel: Kg; brickwork: m2; etc...).

First, we have evaluated the damages created in the quality of the natural ecosystem. Each building has similar installations (bathroom, kitchen, living room, sleeping rooms, etc...), therefore, we are analyzing only six construction units (soil movement, foundations, structure, brickworks, finishes and roofing), because these units have the largest differences when analyzing the impact. More information can be found in "Ciclo de Vida Material. Construcción de nueva planta versus rehabilitación y ampliación en la Vivienda Popular Extremeña". This work has been developed in "La Serena", which is a region in the south east of Extremadura (Spain). We show the general comparison of these two types of constructions. On a second phase, we have analyzed the energetic expenses after the construction process was finished, this way we can value how efficient is each type when they´ll be used. The data is showed per year, in a 50-year life cycle. Finally, we present one of the most important issues for our society, the economical value, answering the main question for this research.

Comparative of Ecosystem Quality impact

The comparative analysis of the case studies (new dwelling versus renewal-extension of a dwelling) is presented by categories and areas. With the obtained results, we can understand that renewing and extending a dwelling has less impact than building from scratch. A first graph shows the impact in several areas (human health, quality of the natural ecosystem and resources).

In all areas, the damage by square meter in renewed and extended dwelling will be 60% lower than in a new construction. In terms of quality of the natural ecosystem, it's 2,7 times lower than in the worst case scenario. For human health is 3,45 times lower, and for resources it's 3,13 times lower than what is produced by square meter compared to a new dwelling built from scratch.

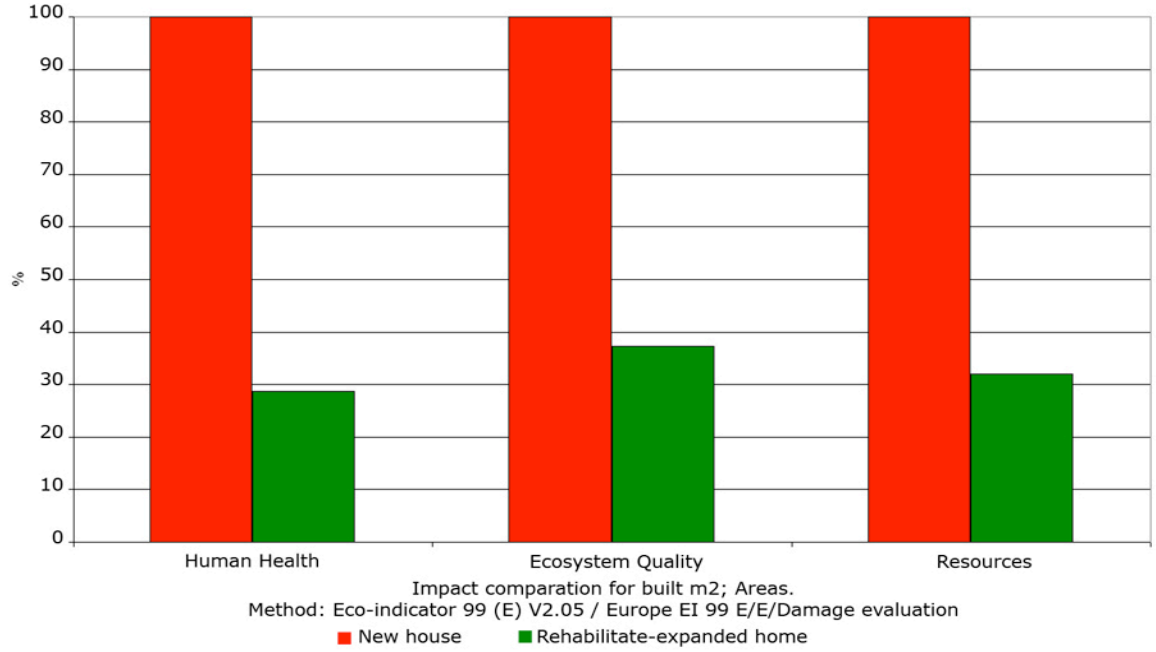

Figure 1: *Impact comparison by areas between new dwelling and renewed-extended dwelling*

In the graphic of comparison by categories, we can find the specific impact in kg.eq.CO2 emitted by each square meter and we can see the originating causes. This graph shows three categories that are more relevant than the rest (from lower to higher): climate change, inorganic breathing particles and fossil fuels..

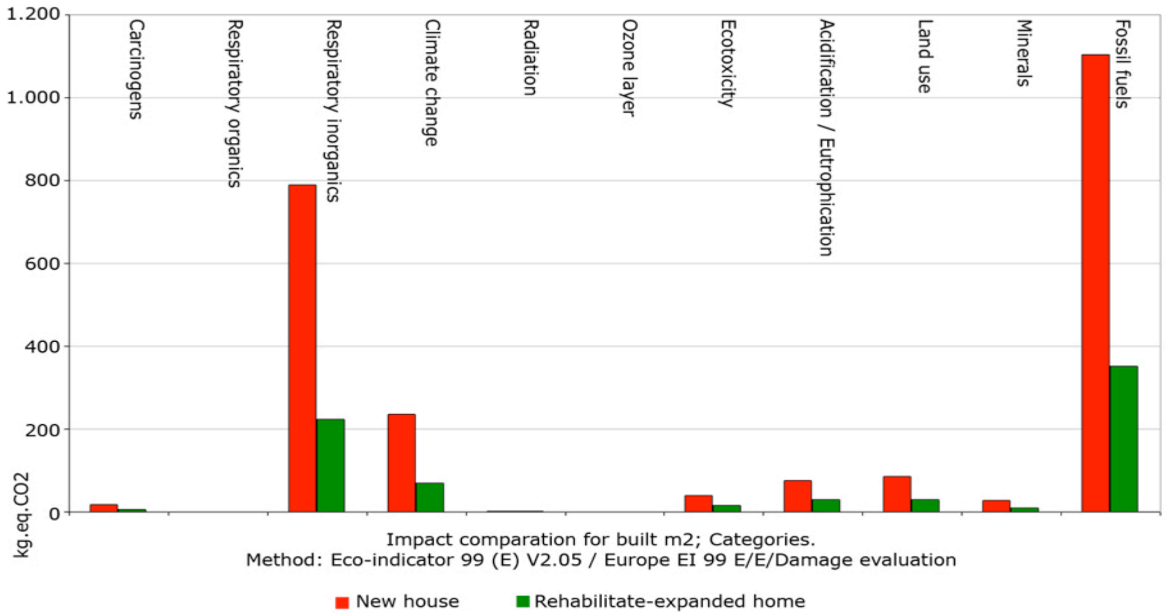

Figure 2: *Impact comparison by categories between new dwelling and renewed-extended dwelling*

This research has the exact value for each construction unit, for more information please consult on the book. Now, for a better comprehension, we show the uncertainty graph of Monte Carlo. This way we will know which are the originating causes for the emission of kg.eq.CO2 on each category for new dwelling or for a renewed-extended dwelling. In the analysis, the values from the renewed-extended dwelling (green) are subtracted to the values of the new dwelling (red).

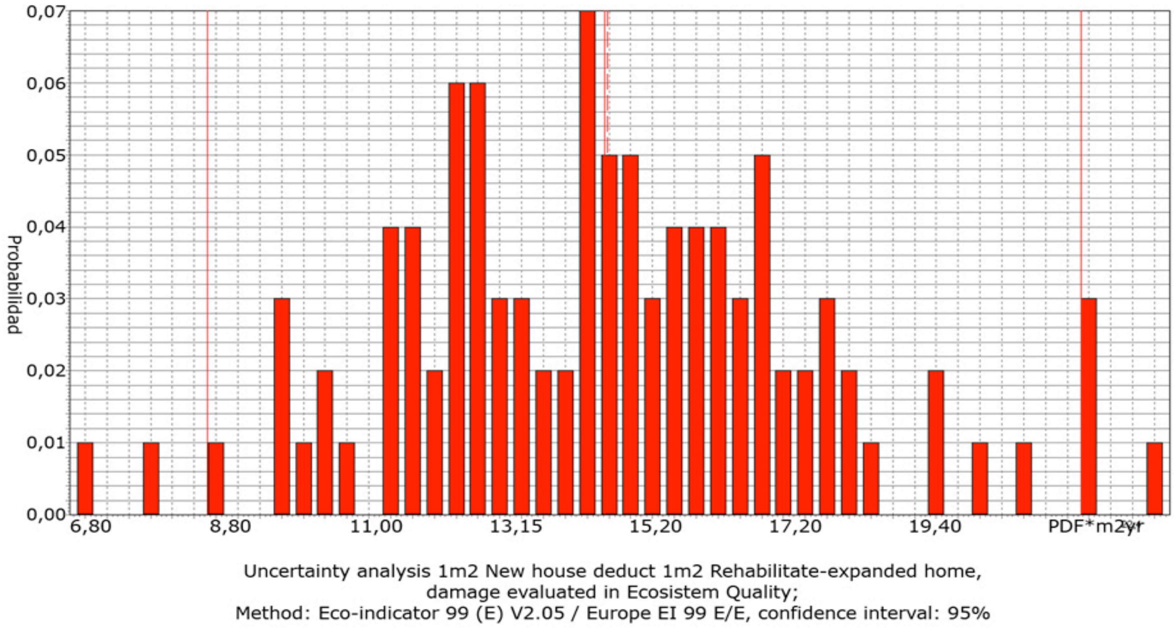

Figure 3: Uncertainty analysis. Impact on the quality of the natural ecosystem for each m2 built of new dwelling versus m2 of renewed-extended dwelling.

In the comparison, there are construction units with a proportional relationship lower than 9,35 times. It's the case of brickwork and roofing. The reason for this is that in these units, most of the materials are reused form other constructions or from the renewed dwelling itself (bricks, roof tiles, sand, clay, wood or sticks). In the case of the external finished, the relation is 2-3 times, because even if we reutilize sand and clay we need lime to make the mortar (in some cases, we will need cement and steel too). Lime has a lower impact, but this material (and it happens the same with cement) requires transformation process to be able to use it for construction. Finally, our goal for this research study in the comparison between new versus renewed-extended and this last aspect (extension) is the reason why there is a bigger impact in this unit, **as shown in Table 1.**

Table 1: Uncertainty comparative newly built dwelling and a renewed-extended dwelling (Kg.eq.CO2)

	New house	Renewed-extended dwelling
Foundation	7,060	4,790
Structure	14,640	7,060
Masonry	9,650	0,770
Roof	6,480	0,700
Cladding-finishes	7,430	2,790
TOTAL SUM	45,260	16,110
All built work package	**45,58**	**16,67**

The average value of the total comparison shows that each square meter of newly built surface has a level of emissions of 2,73 times versus surface of a renewed-extended dwelling. Also, with an approximate calculation, we can obtain a comparative value of new versus renewed; if the dwelling is not extended, we need don't need to make new foundations. In this case, the square meter of renewed dwelling has 4,79Kg.eq.CO2 less of emissions. If we subtract in the structure of the building a part of the concrete, steels and pre-fabricated elements, the renewed dwelling will have an impact 75% lower. This way, the emissions of Kg.eq.CO2 generated by the structure would be 1,82. In other construction units we should also subtract some elements, but these data values are enough to demonstrate how much lower the impact would be. Still, discounting these values, renewing a dwelling would generate 6,08Kg.eq.CO2 versus 45,26Kg.eq.CO2/m2 of the new construction. Therefore, we can see how the impact of the renewal would be much lower; precisely 7,24 times lower.

Comparative energy consumption after construction.

The ARCHISUN analysis will give us the energetic expense for each construction, and it shows that the renewed-extended dwelling has a better behaviour. Normally, people think that an architecture renewal performs worse than a new dwelling, but as we see in the following table, it can be seen how this popular concept is wrong, it all depends on a good design before constructing or renewing. Considering that both projects were thought of as efficient designs, we can observe more favorable values when we renovate re-using local materials versus building with conventional materials (concrete from a factory, steel from who knows where, wood form another continent, etc...).

Table 2: Comparison of energetic consumption once the construction works are finished

GENERAL DATA	NEW HOUSE	RENEWED-EXTENDED DWELLING
Volume:	893.00 m^3	840,96 m^3
Peoples:	4	4
Building use::	permanent housing	permanent housing
Median temperature sensation winter:	10.89 ºC	11,63 ºC
Median temperature sensation spring:	22.41 ºC	22,93 ºC
Median temperature sensation summer:	31.10 ºC	31,58 ºC
Median temperature sensation autumn:	24.14 ºC	24,44 ºC
Natural light	7.55 lux	9,87 lux
Acoustic insulation	26.31 dBA	25,61 dBa
Heating:	10.61 kWh/m3 year	4,98 kWh/m3 year
Refrigeration:	4.50 kWh/m3 year	3,60 kWh/m3 year
Lighting:	4.13 kWh/m3 year	4.12 kWh/m3 year
Hot water:	2.28 kWh/m3 year	2,36 kWh/m3 year
Kitchen:	2.01 kWh/m3 year	2,14 kWh/m3 year
Others:	1.29 kWh/m3 year	1,30 kWh/m3 year

Comparative economic cost.

In the current society, this is perhaps the most important comparison for the citizens. We are talking about money, most of the time or maybe always, it's the only issue apparently. Again, as in the previous cases, the table shows that the dwelling built from scratch is more expensive than the renewed dwelling. Therefore, the good values are not only related to the impact in the quality of the natural ecosystem or the energetic expense after the construction process, it also happens in economical terms.

Table 3: Costs comparison between each type of construction. These prices include the costs of labour, materials and required machinery for each construction unit. http://basepreciosconstruccion.gobex.es/

SUMMURY CONSTRUCTION UNITS	NEW HOUSE	RENEWED-EXTENDED DWELLING
P001- Deconstruction and previous work	- €	5.988,59 €
P002- Earth movement	979,03 €	5.864,77 €
P003- Foundation	8.330,88 €	23.646,07 €
P004- Sanitation installation	2.166,87 €	2.215,43 €
P005- Structure	28.486,30 €	5.460,42 €
P006- Masonry	17.487,20 €	7.793,80 €
P007- Cladding-finishes	22.374,43 €	2.244,72 €
P008- Roof	21.884,84 €	2.623,68 €
P009- Paint	4.670,55 €	2.298,96 €
P010- Electricity installation	5.042,32 €	6.679,42 €
P011- Plumbing installation	7.095,49 €	8.392,19 €
P012- Doors and windows	20.436,12 €	11.269,85 €
P013- Locksmith installation	224,75 €	2.773,86 €
P014- Security and health	1.256,52 €	1.238,76 €
BUDGET EXECUTION MATERIAL	**140.435,30 €**	**88.490,52 €**

The most important differences are in the three first units (de-construction and previous works, soild movements and foundations). This happens because in the renewed-extended dwelling included a new basement, therefore these construction units are more expensive. In the rest of cases, reusing materials is cheaper and the most important issue to obtain reduced prices is in the construction. These budget estimations do not include yet the costs of quality control and taxes (porportional for both cases).

INFERENCES AND CONCLUSION

With all the data obtained we can see that the renewed-extended dwelling is cheaper than the newly build dwelling. It is important to understand that we need a well designed process of de-construction and re-utilization of materials to be able to obtain these good results. In a renewal process we first need to know if the existing building is in a ruin condition; this will be a main requirement for the proposal. A building will be considered to be in a ruinous condition when it presents large structural damages or when in needs a partial reconstruction of over 50% of the building. If the existing building is in a ruinous condition, it will be better to completely de-construct it and to re-use the obtained materials in a new construction, either on the same location or in other location, but not too far, in order to reduce the impact in the quality of the natural ecosystem.

The values previously shown give us the knowledge to be able to answer our questions regarding impact on the quality of the ecosystem and the economical costs of building a new dwelling or renewing-extending an existing dwelling:

1. Impact in the quality of the natural ecosystem in a new dwelling is 2,73 times larger than in a renewed-extended dwelling. It is important not to forget that, if we just renew, the impact of a new house will be 7,26 times bigger for each square meter built. The Kg.eq.CO2 emissions are proportional; each square meter of new dwelling will have 45,58 versus 16,67 in a renewed-extended dwelling. This means the **Ecosystem Quality impact is 63,42% less.**
2. The economic cost of a new house (140.435,30€) versus a renewed-extended dwelling (88.490,52€) is **36.9% cheaper**. Any person would want to renew a dwelling if they knew that the costs are lower than purchasing a new house.

EMPIRICAL DEMOSTRATION, APPLIED RESEARCH, PRACTICE WORK.

We decided to work at the neighbourhood called "El Cerrillo" (Castuera, Spain). It's the oldest and most traditional area of this village. We investigated private and public spaces, types of dwellings, age,

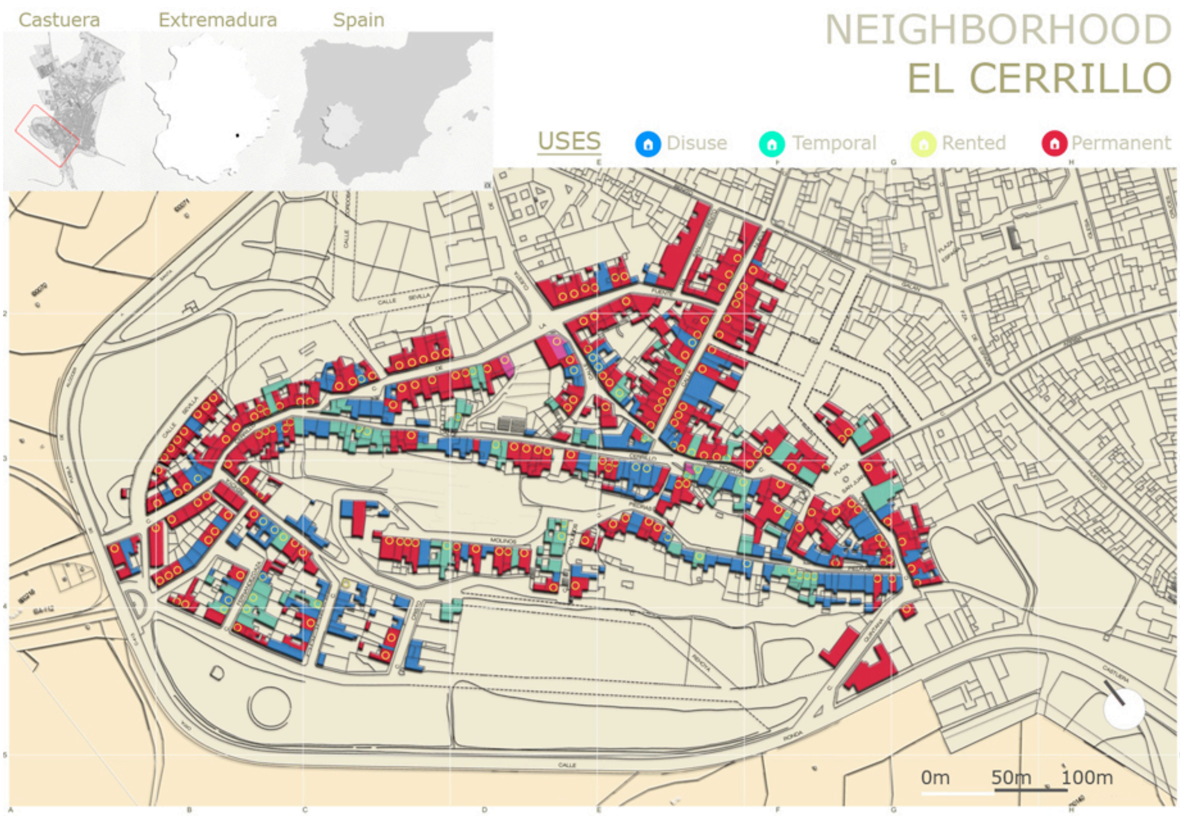

Figure 4: *Used and non-used dwellings in the neighbourhood of "El Cerrillo" (Castuera, Spain)*

materials and the most important of all, the quality and the potential of each dwelling. We found 407 dwellings, 222 with permanent use, 112 non-used and 73 dwelling in rental regime or temporal use.

Many dwellings are in good conditions and a renewal process would be feasible. That is why, in the following step, we went to dwelling built upon traditional and popular technics from Extremadura, where we can work and obtain empirical results about DECONSTRUCTION + REUSE = NØ WASTE.

We worked at the dwelling located at C/Colón 36 (Castuera, Spain). The goal is to un-build the roof (tiles, soil, sticks, wood desks, nails and wooden beams) and adobe walls; **as shown in next figure.**

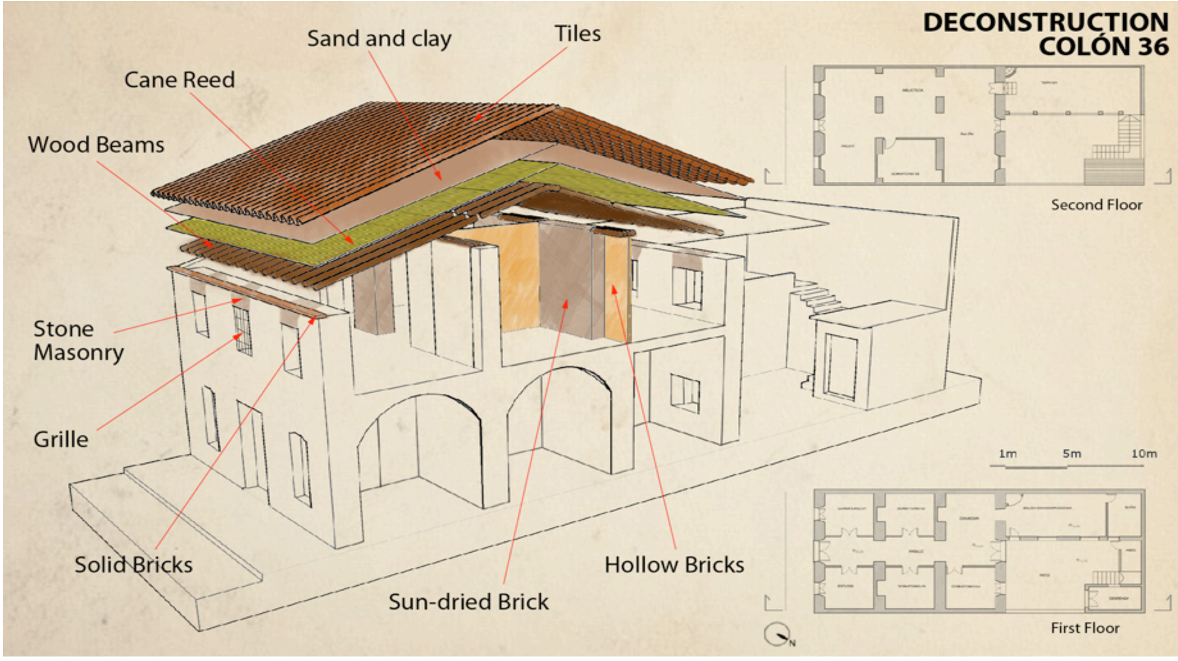

Figure 5: *Deconstruction process.   www.architectureindevelopment.org/project.php?id=354*

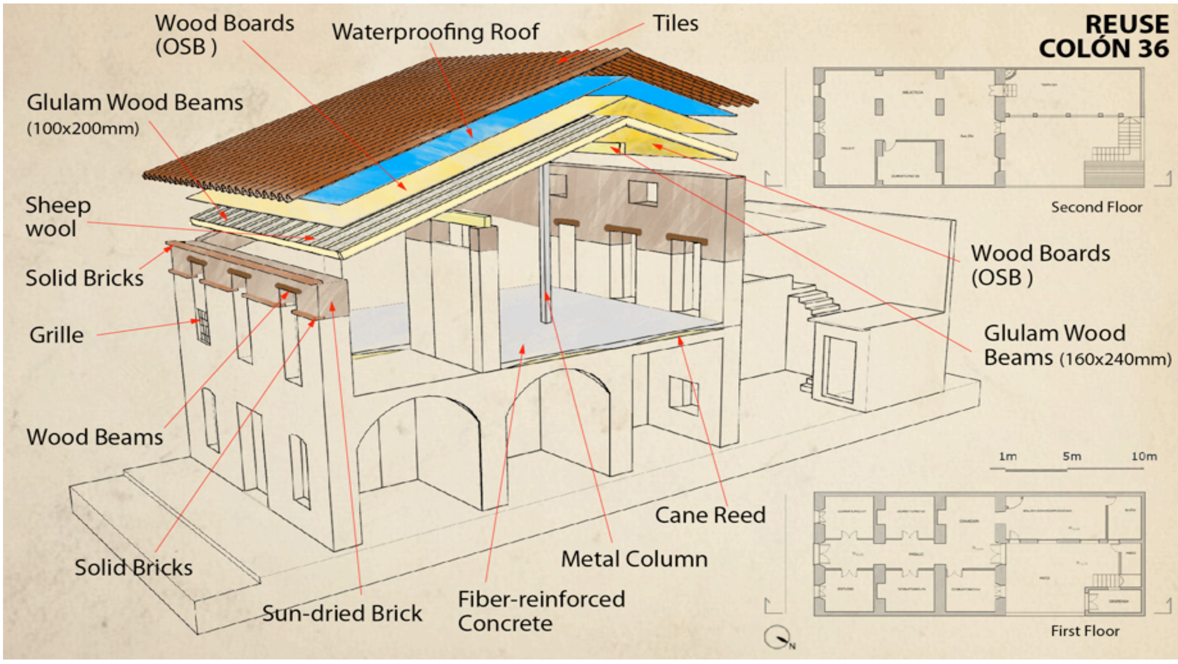

Figure 6: *Reutilization processes.   www.architectureindevelopment.org/project.php?id=354*

Before deciding for the reutilization, we test the materials (trength and durability). We will be able to reutilize 65% of the roof tiles for the same function, and the rest for different functions than the original one (filling up walls, or noise isolation in the fundations). The adobe can be used to increase the walls in the perimeter. Soil as a fill up material in walls, to join the adobe with the facade mortar. The sticks were used as formwork, creating the dome to improve the weight distribution in the structural part of the 2nd floor and carry the loads to the walls of the first floor.

Wood beams to make windows and door lintels and support wood pieces **as shown the Figure 6**. The clapboard and nails were used to build alveolar slab wood, where we use new wood boards (OSB) and glulam wood beams. The insulation is solved with natural sheep wool, using local materials.

Thus, we obtained our goal, this is one of the many works that we have done, after research "Ciclo de Vida Material", we have done in Proyecto áSILO; with the hope that these results can be useful in other parts of the world.

Figure 7: *left photo: inside the dwelling. Right photo: main facade; Colón 36, Castuera (Spain)*

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NOMENCLATURE

kg = kilogram
eq = equivalent
CO2= carbon dioxide
m^2 = square meter
m^3 = cubic meter
% = percentage
ºC = Celsius degree
kWh = kilo Watts hour

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Building a Generic Methodological Framework for a Sustainability Tool Tailored for Architect-Designers

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ABSTRACT

Success in sustainable building depends on a number of factors. Within the competency of project participants, it is crucial that architect-designers have the knowledge and ability to adopt the issues of sustainable building into their designs. An approach on the way towards sustainable architectural designs is to apply methods and tools. These tools aim to act as a bridge, an interface between scientific proven knowledge and the daily practice of architect-designers. Although the use of sustainability tools by design teams is increasing, the present state of contemporary designs regarding the full scope of sustainability indicates a gap, an inadequacy of existing tools.

The target of this research is to build a generic methodological framework for a sustainability tool specifically tailored for architect-designers. First, a literature study identifies specificities of determining factors, resulting in supposed criteria for aimed tool. Second, a review on existing kinds of sustainability tools is carried out. Synthesized issues are pointed out and the assumed inadequacy is verified. Third, an outlook is proposed. Based on identified criteria and issues, a presumed promising concept for aimed tool is delimitated and a set of starting points for the further development are selected. Finally, a proposition for the generic methodological framework is formulated.

The result of this exploratory study is a confirmation of the hypothesis that prevailing up front kinds of sustainability tools are inadequate for architect-designers. Suggested generic methodological framework is seen as a possibility for the development of an operational sustainability tool specifically tailored for architect-designers.

INTRODUCTION

The demand and urge for sustainable development has been increasing the last decades. Due to the multi-dimensional complexibility of the concept of sustainable development in combination with the complexibility of the building sector, the gradation of multidisciplinarity and the size of project teams are expanded. In response, the need for well-understood planning and design processes of sustainable built environments has also been increased (Abdalla et al., 2011).

On the top of critical success factors for delivering a sustainable project is the competency of project participants (Bakar et al.). Whatever the ‘project delivery system’ is, it is seen that the architect-designer fulfills a central role in the project team (Molenaar et al., 2009). As a consequence and by extension, it can be stated that the architect-designer plays a crucial role in delivering sustainable built environments.

A generic and ever expanding approach on the way towards sustainable building is to apply methods and tools. These enable the planning team to identify the effects and interactive relationships of social, economic and ecological dimensions, and deal with these in the planning and/or construction process. (Hegger et al., 2008, p.191). Despite the huge range of tools on the market, the awareness of their existence and the increasing implementation by project teams, the built environment still indicates a gap regarding sustainability. This gives rise to the presumption of an inadequacy of existing methods and tools for sustainability. Given the earlier stated central role of the architect-designer, this inadequacy could be related to incompatibilities, and/or contradictions between the user and the method / tool.

Given a transition towards a sustainable built environment is necessary and architect-designers display a wavering approach, a specific tailored tool for architects is desirable, advisable, and could be successful. The primary objective of this paper is the development of a generic methodological framework for a sustainability tool specifically tailored for architect-designers.

In order to develop a tailored tool, the aimed user has to be known, identified and recognized. First, a literature study identifies specificities of determining factors, resulting in supposed criteria for aimed tool. Second, a review on existing kinds of sustainability tools is carried out. Synthesized issues which the aimed tool should address are outlined. Third, an outlook is proposed. Based on identified criteria and issues, a presumed promising concept for aimed tool is delimitated and a set of starting points for the further development are selected. Finally, a proposition for the generic methodological framework is formulated.

This paper adds to the knowledge of sustainability tools. By explicitly taking into account and focusing specific features of the architect-designer and the process of designing, it stresses the need for a new approach for, and development/ discussion of tools within the field of architectural designing.

This paper is derived from the first part of an ongoing doctorate dissertation on sustainable group housing projects (Janssens, ongoing). This specific research is an explorative attempt for the building of aimed generic methodological framework rather than a research with strict conclusions. The outcome is tentative and preliminary and needs further discussion and verification, both in the fields of academics and practitioners. Outcomes highly depend on conducted literature study of selected corpus of sources, and are not supposed to be salutary or the only possible ones.

DEVELOPMENT OF SUPPOSED CRITERIA FOR AIMED TOOL

Identification of influencing factors

Following aspects are believed to affect the composition of criteria: 'the architect-designer' as the actor, 'designing' as the activity, 'the built environment' as the object and finally the aim of 'a sustainable development'.

The object: the built environment. The built environment relates people to spaces through built forms. It ranges in scale from interiors, buildings, neighbourhoods to districts and cities, including their supporting infrastructure. It refers to a broad-ranging interdisciplinary field that addresses design, construction, management and use. The built environment could be defined as the human-made space or surroundings that provide the setting for human activity, live – work – recreate, on a day-to-day basis. It comprises an infinite variety of functions to meet the endless range of human interests and proclivities. In another sense, the built/constructed environment involves some of the most elaborate forms of artifice—varieties of materials, complex engineering, infrastructures of technical interconnection and relationships to nature. The built environment refers to a practice-oriented discipline, in which the end product is a material, spatial and cultural product of human thinking and labor, taking into account interactions among the constructed, social and natural environments.

The aim: sustainable development. The essence of sustainable development is to provide for the fundamental needs of humankind in an equitable way without doing violence to the natural systems of life on earth (Kemp & Martens, 2007). Following Our Common Future (WCED, 1987), numerous efforts were made to operationalize the concept. The most common is the triangular representation with three pillars 'environment', 'society' and 'economy'. In some contexts these pillars come to be referred to as 'Planet, People, Profit' (Elkington, 1997).

Concerns for the relationship of humans to environment, natural and built, increasingly deploy the rubric of sustainable development, making it one of the fundamental concerns of contemporary times. The definition of Our Common Future has been interpreted in many ways, caused by the fact that the vision and the description are linked to many different aspects. Some interpretations give the notion that sustainable development is a specific field or discipline, other emphasizes the dynamics emerging from different imperatives. Either way, the vision concerns complex, multi-disciplinary problems that have to be handled from both holistic and analytical approaches.

The activity: designing. Despite real differences between the end products created by designers in various domains, design can be seen as a generic activity: ‘Many forms of design then, deal with both precise and vague ideas, call for systematic and chaotic thinking, need both imaginative thought and mechanical calculation’ (Lawson, 2005, p.4). Nevertheless considerable revisions about design theory, several authors claim that our current understanding of design is still incomplete. This does not imply that designing is mysterious and obscure, but that it is complex (Lawson, 2005). Tjallingii (Tjallingii, 1996) states that designing is the creation of promising combinations and opportunities regarding the physical context, the use and management.

The actor: the architect-designer. The working field of the architect-designer is the built and yet to build environment, ranging in different scales and specialties. Literature is vague and apparently no one feels able to offer a succinct description that they are confident would be widely agreed upon and yet fully describe the work of all architects. Lawson (Lawson, 2004, p.1) states: ‘It is quit impossible to find two people who call themselves architect and yet hardly share any of their daily tasks’. Following Lawson (2005, p. 4), the working field of the architect-designer lies near the middle of the spectrum of design activity. Design in the built environment requires both technical knowledge and expertise, as well as visual imagination.

Pinning down synthesized features of actor and activity factors

Factors of the actor (the architect-designer), and the activity (designing) are complex and heavily loaded. A commonly accepted defined framework is inexistent. However, for the purpose of this research, a self-compiled set of widely subscribed features was made, backed by selected corpus of relevant sources. Synthesized features are provided in table 1. Within the scope of this paper, providing referencing notes on displayed features is not possible. Therefore only general references are given: Cross, 2006; Lawson, 1980; Lawson, 2004; Lawson 2005; Rehal, 2002; Van Dorst, 2005.
Classified features may not be seen as strict, as there is a strong overlap in, and interdependence of, characteristics of the ‘architect-designer’ and ‘designing’.

Table 1. Synthesized features of actor and activity.

The actor: ‘the architect-designer’	The activity: ‘designing’
Explicit & implicit knowledge	Exploratory & satisficing
Different levels of expertise & experience	Responsive & integrative
Complexity management	Convergent & divergent
Solution focused	Resultant, emergent & abductive
Metaphoric appreciation	Reflective (simulating) & ambiguous
	Iterative, personal & unique
	Narrative & imagery

Cross-factor reflections

Sustainable building is a combination of disciplines, a necessary package deal to prevent us from trade off effects. This complexity describes the problems of sustainable development and at the same time shows the daily practice of an urban designer or planner. The practice of finding ‘promising combinations’ (Tjallingii, 1996) is the common ground for sustainable transition and design. In a designerly way of thinking one combines possible solutions from disciplines which are by nature different (Van Bakel, 1995) (Cross, 2006).

In both aspects, built environment and sustainable development, there are no right or wrong answers. Actions must be decided in process of negotiation and dialogue, and the long-term perspective is central within the quest. Lundeqvist (1995) and Edén (2002) conclude that features of sustainability resemble, in general, any traditional design problem. Because the similarities between features of the built environment and sustainability, and the architect-designers ability of dealing with complexibility and multi-disciplinarity makes him suitable to deal with the sustainability quest. Despite sustainability is often dealt by, or pushed off to, a wide range of project partners, the architect-designer can and should take up the mandate in view of sustainable successes in a designerly way. Both aspects, sustainability and the built environment, are so complex that chances for success largely depend on the knowledge, a deep understanding and experience of the architect-designer. It is important that this knowledge and experience building is supported, made possible and not prevented or penalized.

Supposed criteria a tool should comply

This final subsection provides an overview of criteria which a sustainability tool for architect-designers is supposed to comply with.

Table 2. Supposed criteria for aimed tool.

Supposed criteria	Description
Random usability	• No mandatory, design activity structuring successive process: free timing of startup, enter and use, free consultable, allowing an iterative, cyclical or linear process. • Allowing using different design approaches. • Serving an incremental and radical optimization of (yet to be) designed / built environments. • Meeting architect-designers' diversity: suitability to preferences and difference in levels of expertise.
Apprehensible communication	• Ensuring a transfer of knowledge and insights to the architect-designer (primary user of tool). • Ability to act as a discussion platform for project actors. • Providing an attractive/suitable display and representation of the content (photo, sketch, ...).
Problem framing	• Providing background information: identification, structuring and limiting of the problem. • Setting boundaries for the design problem (and solution): support the development of the brief. • Connecting partial problems, mutually and with the design process.
Solution focused moving	• Displaying principles, measures, concepts, combinability's. • Providing non- and contextualized exemplary solutions: single, multiple and/or integral oriented.
Source of knowledge and insights	• Inclusion of scientifically and practically proven knowledge. • Linking theoretical knowledge with practical relevance.
Enabling innovation	• Indicating the need and importance of verifying displayed facts and building episodic knowledge/insights • Stimulating knowledge building by designing. • Incorporation of incentives for own research.
Non-limiting	• Safeguarding creativity and unicity of design/project. • Space for interpretation, implicit knowledge/experience. • Balancing between prescription and freedom/voluntariness: open-ended / non-committal. • Indicating the non-restrictiveness of displayed substantive body of knowledge.

DETERMINATION OF ISSUES OUT OF EXISTING KINDS OF SUSTAINABILITY TOOLS

Identification and description of existing kinds of tools

As there is no strict classification of tools, for the purpose of this section, we suggest a threefold classification. Knowledge based or qualitative tools involve instruments providing guiding principles (e.g. 'Trias-model') on the one hand and guidelines (e.g. 'Practical Recommendations for Sustainable Construction' of the EU) on the other hand. Both kinds are based on proven knowledge and experiences.

Guiding principles offer a simple structure which has to lead to sustainable successes. They formulate generic recommendations, strategies, etc. Guidelines link sustainability in a direct way to decisions, but without offering a structure for the design process. Checklists, catalogues and directives often include targets, criteria and/or measures which can be considered or must be implemented to match set requirements. Performance based or quantitative tools include life-cycle impact assessment, outdoor and indoor social and environmental quality. Quantitative tools can focus on single or a limited amount of sustainability criteria or on multiple criteria. Single or limited sustainability oriented tools (e.g. EcoQuantum) are often developed for scientific research. Aspects of sustainability are clearly defined and demarcated (e.g. energy, material). Multi criteria tools (e.g. BREEAM) are focused on the use by practicing actors in the building sector, aiming to be implemented in practical real-life applications like buildings and neighbourhoods. A matrix assists designers in identifying design criteria, document proposed design performance and calculate the number of achieved credits, leading to an overall rating. Performance based tools, more in specific market oriented tools, can also include a rating system, often supplemented with a certification system and labelling. These labels are used in view of market positioning, recognition, publicity and entitling/obtaining funds, fiscal benefits, subsidies, grants etc.
Ad hoc tools are project specific developed tools. They can be qualitative or quantitative, or a combination of both. Usually these tools are initiated on the occasion of a large scale project like urban regeneration programs, and new neighbourhoods/districts (e.g. PIMWAG-system ECO-VIIKKI, Helsinki, Finland).

Analysis on prevailing strengths/weaknesses and synthesized issues

An exhaustive analysis with regard to displayed classification of existing kinds of tools is not a goal in itself. A quick suitability scan in a general perspective leading to strengths and weaknesses enables uncovering issues. Table 3 provides an overview. Consulted authors are: Abdalla et al. (2011), Gowri (2005), Janssens (2013).

Table 3. Prevailing strengths and weaknesses of existing kinds of tools and synthesized issues.

Kind of tool	Strenghts	Weaknesses
Knowledge based tools (qualitative)	• Informative • Assistance in decision making • Preserve freedom and creativity • Mapping sustainability aspects on to components, indicators, measures, etc.	• No / limited and inadequate insights in mutual relations in and between theoretical and practical aspects • Vague descriptions • Comprehensive elaborations
Performance based tools (quantitative): Multi criteria	• Presumed integrality > • Presumed accessibility > • Indicator for quality's > • Measuring is knowing >	• Limited sustainability scope • Degree of expertise required • No guarantee for successes • Dubious quantifiability of criteria / scoring / weighing • Focus on criteria / indicators • Often misused as checklist
Ad hoc tools	• Project specific tailored >	• Shadow of exclusiveness, exceptionality which is a burden for mainstreaming
Overall	• Identification and definition of sustainability, enabling communication and negotiation	• Dubious effectiveness, efficiency, complexity reduction, up-to-dateness • Susceptible to subjectivity • Extensiveness
	Synthesized issues Preserving objectivity - Providing insights - Attention for manageability – Actual Integrality - Being inspirational	

OUTLOOK FOR A SUSTAINABILITY TOOL FOR ARCHITECT-DESIGNERS

Suitability review and delimitation of a presumed promising concept

This subsection verifies the suitability of two mainstream kinds of tools using two short quotes from literature.

'*The so-called educational tools, including guidelines, rules-of-thumb and best practices seems to be more coherent with the architectural practice, in which the construction of knowledge and decision making is strongly based on referential procedures.*' (Albuquerque, 2007)

'*However, the methods of science are perhaps surprisingly unhelpful to the designer. Modern building science techniques have generally only provided methods of predicting how well a design solution will work. They are simply tools of evaluation and give no help at all with synthesis. Daylight protractors, heat loss or solar gain calculations do not tell the architect how to design the window but simply how to assess the performance of an already designed window.*' (Lawson, 2005)

Design tools are a somewhat controversial subject for architect-designers. Many architects dislike talking about their work process in terms of methods or tools, because it suggests a repetitiveness that is contradictory to creativity. It must be obvious that the specificity of architects, their design methodology and the complexity of designing is so individual that it is impossible to discover an existing or develop a tailored 'tool' which satisfies all. '*Designing is far too complex a phenomenon to be describable by a simple diagram.*' … '*The word "design" is applied to an extraordinarily wide range of activity include at one extreme something that could also be called "engineering" and at another something that could also be called "art".*' … '*Design is a highly personal and multi-dimensional process.*' (Lawson, 2004)

Delimitation of a presumed promising concept

Weaknesses of existing kinds of tools, synthesized issues and previous suitability review gives rise to the development of an innovative concept for aim framework.

- Focus on pre-design and early design considerations and later design inspiration
- Physical – spatial approach instead of a constructive technical approach
- Knowledge based instead of performance based
- Design supporting instead of design process structuring
- Solution focused instead of problem focused
- Knowledge building instead of full exhaustive and limitative display

Selection of a set of starting points for the further development

A description of the complete set of starting points is not possible within the limited length of the paper. As these starting points represents the basis of the further development of presumed promising concept, they will be discussed and documented in depth during the oral presentation. By way of illustration, two important starting points are outlined in this sub section.

General model of high level creative strategies in design. Three key aspects appear to be common in the creative strategies exercised by designers (Cross, 2006). First, taking a broad 'system approach' to the problem. Rather than accepting narrow problem criteria, often set by the client or e.g. regulations, aiming for high-level problem goals. Second, 'framing' the problem in a distinctive and sometimes rather personal way, stimulating and pre-structuring the emergence of design concepts. Third, designing from 'first principles'. Designers either explicitly or implicitly rely upon 'first principles' in both the origination of their concepts and in the detailed development of those concepts.

The phenomenology of concepts. Ramirez (2000) finds it appropriate to operate with three kinds of concepts: ideological, diffuse and compact concepts. The ideological concept hides and idealizes preferred ideas, notions and situations which are desired and may be realistic. Typical political rhetoric is very often dominated by ideological concepts, such as freedom, sustainability, quality, equality and so forth. Diffuse concepts are somewhat ambiguous and often need to be connected to a particular context, situation or experience to be understood. Diffuse concepts refer to phenomena that really exist but are difficult to precisely describe through definitions. Compact concepts are used in science where the studied object is the concrete material world and where unambiguous, well-defined definitions and context independence are the central characteristics. While the built environment is interdisciplinary, all three kinds of concepts are necessary in de design process, whereas a specific order is relevant. Rehal (2002) states: 'In the earlier stages of the process, it is mostly diffuse and ideological concepts that are in focus. When the artefact begins to take shape, the thought process transgresses from diffuse concepts to more compact ones.' This way, concepts are used appropriate to the design stage. Complexity and subjective matters (such as aesthetics, culture, artefacts) which ought to be negotiated during the design process, are kept open as long as possible. The further compact concepts are used or developed, the more the design is ready.

Preliminary proposition for aimed tool

Taking into account the outcomes of explorative study, a process of reasoning, synthesizing and a continued evaluative leap (trial & error) to supposed criteria, results in a preliminary proposition. A knowledge structure is believed to be suitable for aimed generic methodological framework. This design supporting structure can be implemented in a cyclical or linear process of design, for random referencing, backgrounding, inspiration, ideation, and/or for selecting final solutions in whole or in part. The actual deployment of the structure depends on the preferences and level of expertise of the user.

A full description of the proposed knowledge structure is not possible within the limited length of this paper. A detailed and illustrated discussion will be the focus of the oral presentation.

The general outline of the framework approaches a gradation from theory to practice, and from problem to solution.The framework consists of implicit and explicit elements, preceded by a backgrounding and followed by a synthesizing part. Implicit elements are incorporated in the structure and content, while explicit elements are recognizable and distinctive parts as such. Implicit elements are: best real-life practice backed, cross structure referencing, suitable representation techniques, database of knowledge, building of episodic knowledge, transcending the specific, no value judgement, non exhaustive display, combinability's, satisfying and optimizing. Explicit elements are given in figure 1.

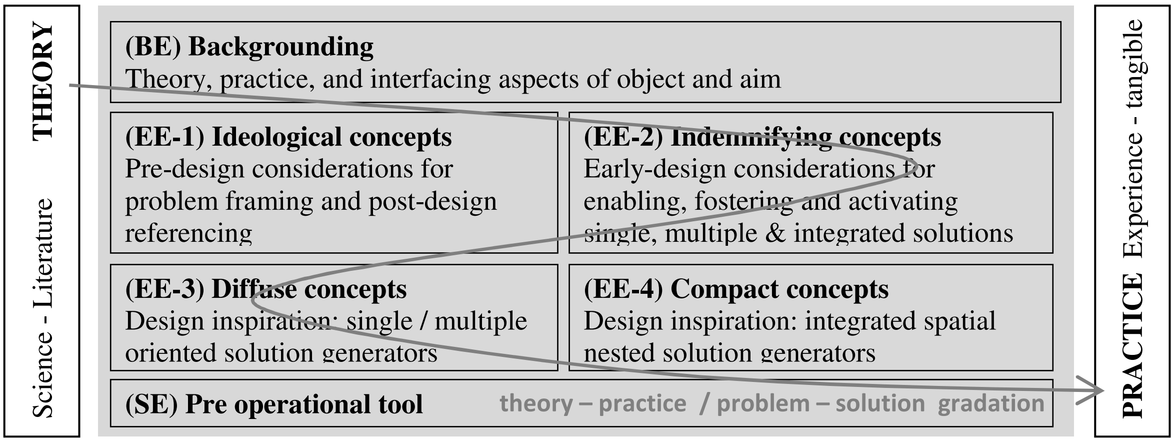

Figure 1 Explicit elements of preliminary proposed generic methodological framework.

FINALIZING REMARKS

Developing a tool, within the sustainability quest for the built environment specifically tailored for architect-designers, is an innovative but complex task. Tentative building and display of proposed framework in this paper must be seen as an incentive for discussion and further research. Experts in this field and related aspects are well placed for verification, adjusting and a further development.

The perspectives at short term are twofold. First, this research will be supplemented with a verification. Preliminary outcomes are to be presented to a selection of practicing architect-designers after which they will be asked to provide feedback. Second, in order to test the feasibility of aimed content of the tool, a specific substantive body of knowledge will be investigated and integrated in the framework. Both perspectives enable an evaluative loop of verification and adjustments, leading to improvements. During this process it is important to constantly safeguard developed and adjusted criteria, and to prevent relapsing in issues of current sustainability tools.

The preliminary result of this exploratory study is a confirmation of the hypothesis that prevailing up front kinds of sustainability tools are inadequate for architect-designers. Suggested generic methodological framework is seen as a possibility for the development of an operational sustainability tool specifically tailored for architect-designers.

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Ventilation Cooling Effects of the Rammed Earth Wall Built in the Hotel Guest Room

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ABSTRACT

In Nov. 2013, a hotel was completed beside the Biwa-lake in Moriyama city, Shiga Prefecture, Japan. This is a three storeyed building with 14 guest rooms. The main structure is reinforced concrete but the rammed earth walls were built as the partitions between guest rooms. The rammed earth, which was made from local and natural soil, was expected to work as a thermal mass for passive cooling in the summer time. Each hotel guest rooms faces to the west and has a good view of the lake. In this area, the prevailing wind in the summer time was west-east, and the ventilation cooling, utilizing this wind was planned. The design of this building was studied based on the results of simulation studies and it was expected to reduce 75% of cooling load. This paper discussed; 1) the design process of this building, 2) the results of simulation studies, 3) the performance of the ventilation cooling effects.

1. INTRODUCTIONAND BACKGROUND

Building low environmental impact architecture, throughout the life cycle, is a form of construction required for the coming years.When you build a building, making buildings that used local natural resources of the land, as much as possible,is the new imperative. Production of soil wall is known for its lesser environmental load or energy consumption than reinforced concrete. Rammed-earth,which is made by pressing soil inside frames, has a beautiful layered texture and humidity conditioning, and large thermal capacity. Then, we can use this wall, indoors, as a thermal mass to reduce heating and cooling load. In the former investigation we made experimental building with rammed earth in Kobe, then simulated and measured the thermal performance of the building. We presented how to use the rammed earth as thermal mass in the area.

In Nov. 2013, a hotel was completed beside the Biwa-lake in Moriyama city, Shiga Prefecture, Japan by Architects Ryuich Ashizawa Architect & Associates, and Soil-wall consultants, Kumiko Hatanaka design office, as shown in **Figure 1(a)**. This hotel has 3 rammed earth partition walls, as shown in **Figure 1(b)**. The authors investigated with the former method how many cooling load this rammed earth reduced. Furthermore, for more effectiveness, the effect of passive cooling by outside air intake was subjected to ventilation simulation in order to determine the opening position.

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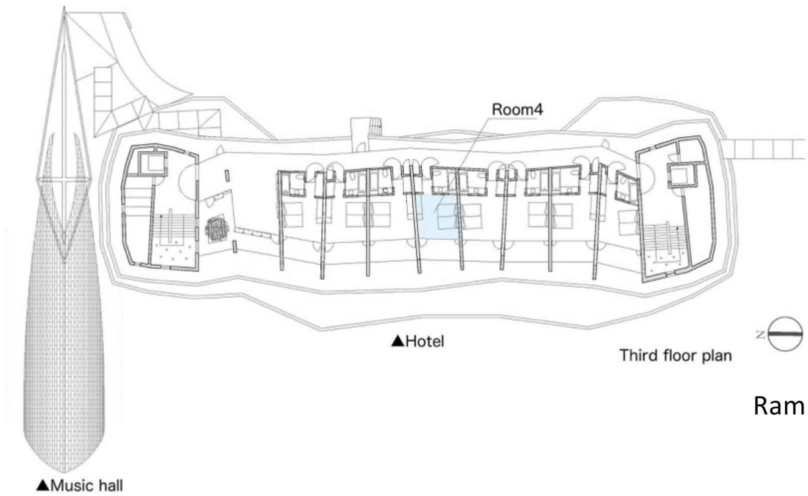
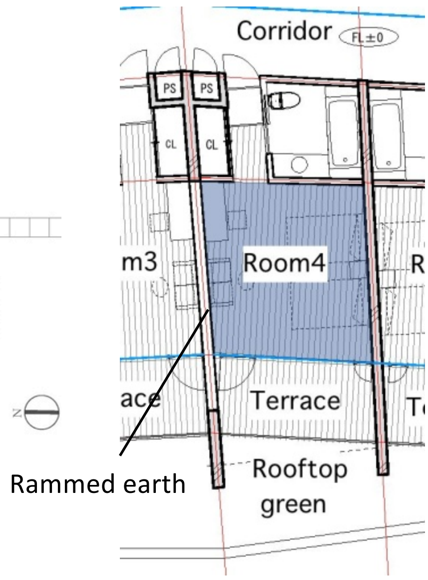
a) The Hotel and Music hall b) Guest room 4

Figure 1 a) West face of the hotel seen from the lake. A music hall is on the left side of the hotel, b) The guestroom on the right wall is a rammed earth.

2. DESCRIPTION OF THE ARCHITECTURE

The hotel has three stories with fourteen guest rooms, one restaurant and one banquet room. The hotel has a wide view to the lake in the west. The Music hall that is used mainly for wedding ceremony is on the north to the hotel. The walls of the guest rooms are built with reinforced concrete except one. The floors are made by raised wood. Rammed earth walls are used as partition for rooms.The room has a rammed earth wall in the north or south. The windows are designed to ventilate from the west, the lakeside to the east, as shown in **Figure 2(a) & 2(b)**.





a) Main plan b) Part plan

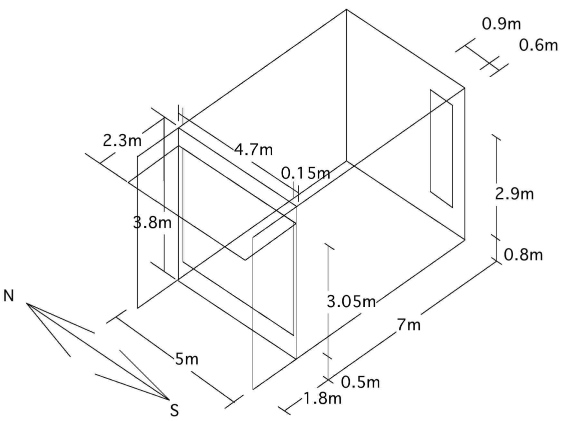
Figure 2 a) Music hall and 3rd floor plan and target room 4 for simulation, and b) Part plan of hotel room, Room 4

3. SIMULATION FOR THERMAL PERFORMANCE IN SUMMER (GUEST ROOM)

3-1. Simulation Model and Method

Although the forms of 14 guest rooms are varied, we computed the cooling load of “Room 4”,as shown in Figure 2(b), in the summer as a typical room. The room is twenty two square meters wide. The plan and elevation is distorted. The room is four metre wide on the west side. Although there is a bathroom and a closet in the east, for the simulation we assumed it simple form regardless of the parts. **Figure 3(a) & 3(b)** shows common details of the shape and specifications of room to simulate. We show the result of simulation on next page. On these information shown below, we varied materials of thermal mass.

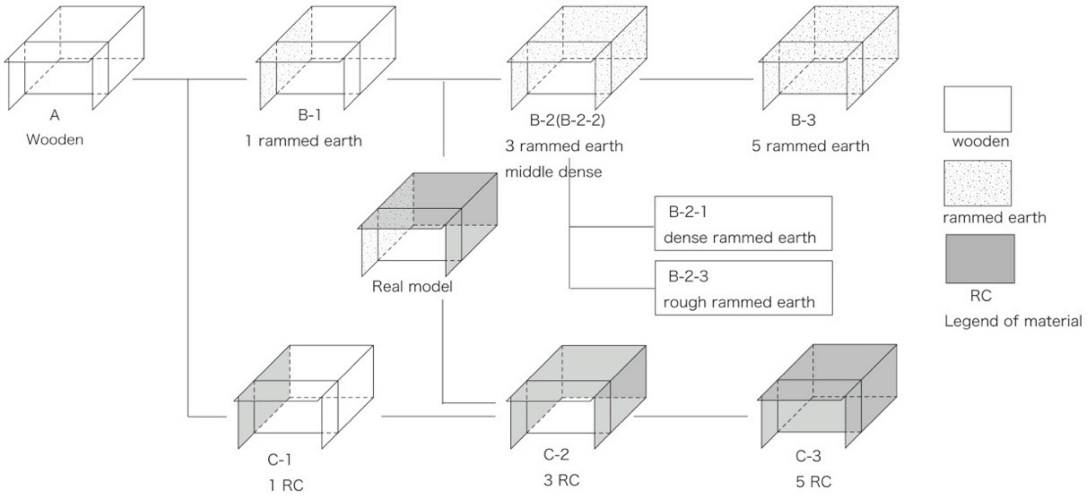
The room was considered to be 4m wide, 4m deep, and 2.5m high. The opening of terrace side is made with double glazing in wooden frame. The wall thickness of guest room is 250mm, so we simulated considering that there are no heating affect by the next room which shares the wall as well as upper or lower rooms. Therefore, other than the west face, a glass wool of 500 mm thick on the outside of the Thermal mass was considered. We set 2.3m depth eave which is positioned over the terrace and 1.8m length on the sidewall of the terrace. As internal heat, we set 210J/h from refrigerator constantly, and 882J/h from two hotel guests who stay between 17p.m. and 8a.m. in the guestroom. We assumed that during the night time, between 18p.m. and 7a.m. a curtain would be closed as a night insulated door and when the outdoor temperature is between 18- 26 ºC, the outdoor air inlet would be open. In this case, simulation model is Room 4, which is call “Real model”. There is a rammed earth wall at north side wall. The floor was covered with a wooden floorboard. The west side have big window. The walls of guest rooms are built with reinforced concrete except one, as shown in **Figure 3(a) & 3(b)**. The thermal mass material is changed, and what kind of cooling load, was calculated according to the flow diagram, as shown in **Figure 4(a)**. Material constituting the respective models, are as shown in **Figure 4(b)**. Material properties are, as shown in **Figure 4(c)**. We simulated the thermal performance with the design tool “Solar Designer ver.6” developed by the authors.



form		width 5 × depth 7 × hight 3.8(m) raised floor
eaves		depth: 2.3(m) hight: 3.35(m)
wing wall	north side	length : 1.8(m)
	south side	length : 1.8(m)
east window	size	width 0.9 × hight 2.9 (m)
	position	from floor : 0.8 (m)
		from north side : 0.6 (m)
west window	size	width 4.7 × hight 3.05 (m)
	position	from floor : 0.5 (m)
		from south side: 0.15 (m)
glazing specifications	glazing	double glass (A12)
	thermal transmittance	2.901 (W/m2K)
	solar transmittance	0.737
thermal mass thickness	floor	0.03 (m)
	wall	0.25 (m)
	ceiling	0.25 (m)
insulation thickness	floor	0.5 (m)
	wall	0.5 (m)
	ceiling	0.5 (m)
insulation	thermal conductivity	0.039(W/m・K)
	volumetric specific heat	20.09(kJ/m3K)
indoor solar absorptance		floor,wall,ceiling : 0.4
outdoor solar absorptance		floor,wall,ceiling: 0.4

a) The model used for simulation b) The data used for simulation

Figure 3 a) Specifications of simulation model of “Real Model”, b) Data used for simulation



a) Simulation flow

Model name	sub name	South wall	East wall	Noth wall	West wall	Ceiling	Floor
A	Wooden	W	W	W	G	W	W
B−1	1 rammed earth	W	W	RE	G	W	W
B−2−1	3 rammed earth/ dense	RE	RE	RE	G	W	W
B−2−2	3 rammed earth/middle dense	RE	RE	RE	G	W	W
B−2−3	3 rammed earth/rough dense	RE	RE	RE	G	W	W
B−3	5 rammed earth	RE	RE	RE	G	RE	RE
Real Model	—	RC	RC	RE	G	RC	W
C−1	1RC	W	W	RC	G	W	W
C−2	3RC	RC	RC	RC	G	W	W
C−3	5RC	RC	RC	RC	G	RC	RC

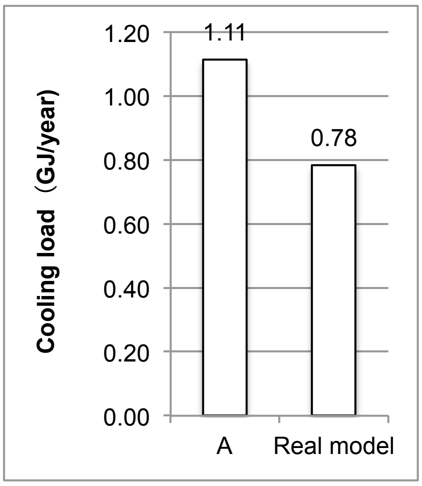
W:Wooden RE: Rammed earth RC:Reinforced concreat

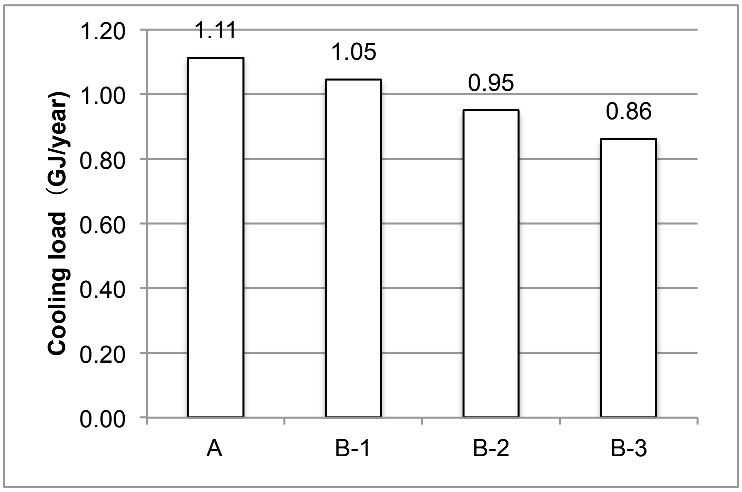
Wooden	thermal conductivity	0.15(W/m・K)
	volumetric specific heat	714.9(kJ/m3K)
Rammed earth (B−2−2)	thermal conductivity	0.58 (W/m・K)
	volumetric specific heat	1130(kJ/m3K)
RC	thermal conductivity	1.51(W/m・K)
	volumetric specific heat	1883(kJ/m3K)

b) Materials of each models, c) Thermal mass material properties

Figure 4 a) Simulation flow, b) Materials of each models, c) Thermal mass material properties

3-2. Thermal performance in summer

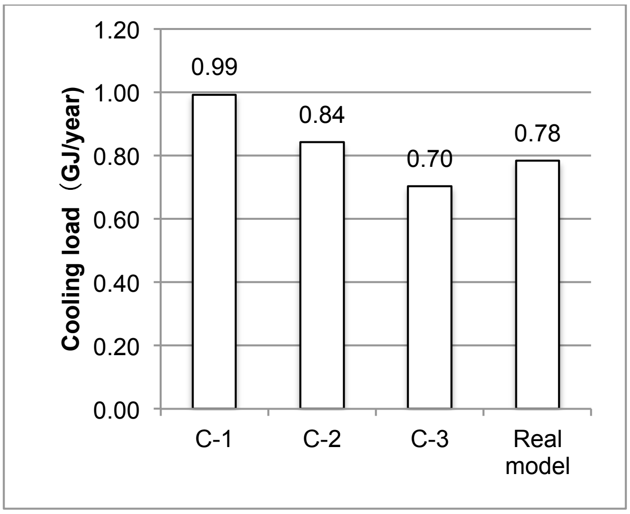


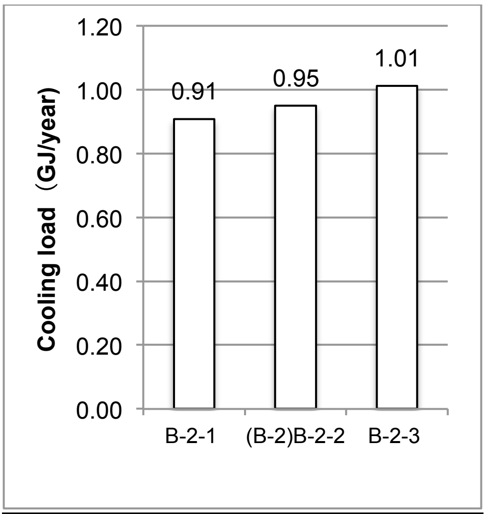


a) Model types A & Real model b) Model types A & B

Figure 5 a) Annual cooling load for A & Real model, and b) Annual cooling load for A & B types

Figure 5(a) shows the comparison of the cooling load for "model A", made in wood (plywood),as shown in **Figure 4(a), 4(b), 4(c)**, with the "Real model", as shown in **Figure 2(b)**. Rammed earth thermal mass walls are expected to work well for the cooling load. B-1 has a rammed earth wall in the north side, and the rest of the walls of the guest room is built with wood, as shown in **Figure 4(a), 4(b) & 4(c)**. B-2 has 3 rammed earth walls. B-3 has 5 rammed earthwalls, as shown in **Figure 4(a), 4(b) & 4(c)**. The analysis shows that the cooling load decreases with increase in rammed earth walls, as shown in **Figure 5(b)**. **Figure 6(a)** shows thermal mass works well for the cooling load. C-1 has one reinforced concrete wall in north side and the other walls are built with wood, C-2 has 3 RC walls, C-3 has 5 RC walls, as shown in **Figure 4(a), 4(b) & 4(c)**. In this case also, the cooling load decreases as the amount of RC walls increase, as shown in **Figure 6(a)**. **Figure 6(a)** shows comparison of cooling load for "Real model", which has wooden floor and one rammed earth wall. So, it has less thermal mass and a little bigger cooling load than C-3. But "Real Model" has less cooling load than C-2.





Material	Thermal conductivity (W/m・K)	Specific heat capacity (kJ/m3K)
B−2−1 Dense rammed earth	0.70	1381
(B−2)B−2−2Middle dense Rammed earth	0.58	1130
B−2−3 Rough rammed earth	0.47	837

a) Model C-types & Real model b) Model B-types comparison and material properties

Figure 6 a) Annual cooling load for C types & Real model, b) Annual cooling load for B types and Thermal conductivity and specific heat capacity of rammed earth with various density.

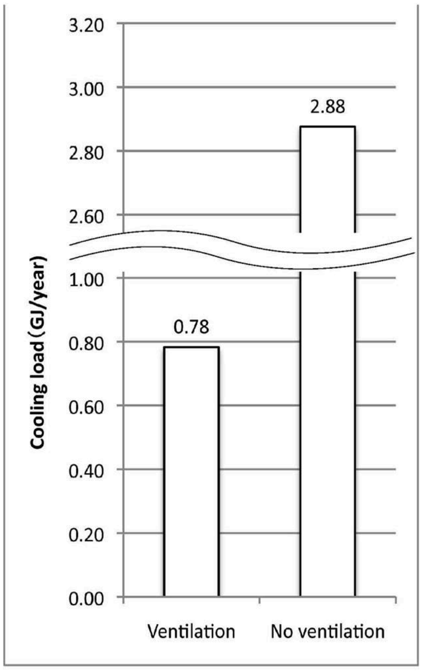


Figure 7 Annual cooling load / Ventilation mode and no ventilation mode

Rammed earth has various conditions determined by what the type of soil used, and how hard the earth was rammed. So,we considered three different thermal conductivity and volumetric specific heat of rammed earth: Rammed earth 1 is high density; Rammed earth 2 is mid density; Rammed earth 3 is rough, low density. **Figure 6(b)** shows that as the density of the rammed earth increases, the cooling load is lower. The cooling load comparison of the cases shows that in the dense version built, the cooling load is reduced. In case of the "Real model" the cooling load decrease, if we compare to **C-1 & C-2** modes. When only active cooling is used windows are closed and air change rate of 0.5 times per hour is considered, and when the outdoor temperature range is 18~26ºC, 15 ACH, natural ventilation is used. The simulation results of 3 ways using,ventilation mode and non-ventilation mode, and cooling load is reduced by 75% in ventilation mode, as shown in **Figure 7**.

3-3. Conclusion

This examination shows ventilation is effective to be used in the guest room to reduce the cooling load. And Rammed earth is an effective material to reduce cooling load and embodied energy. Then, rammed earth is the next generation's material. And,the simulation is an effective tool for verification of the same.

4. DESIGN OF THE WINDOW (GUEST ROOM)

4-1 Simulation Model and Method

The thermal environment simulation, showed cooling load reduction and the ventilation cooling effects obtained by taking advantage of the heat storage of the rammed-earth wall. Night ventilation takes in the cold air of the night, and stores it until the next day. For this purpose, it is necessary to ventilate an appropriate amount while considering appropriate security and privacy. In this section, we describe the design of the opening to ensure a desired flow distribution and airflow, and introduce the simulation results of the flow.

Western windward side is a picture window to capture the views of Lake Biwa. In order to retain the view, a window for ventilation was provided for at the position of the feet.The louver door installed at the east entrance leeward location was designed to allow wind flow, and through the common corridor, as shown in **Figure 8(a) & 8(b)**.Under these conditions, we investigated the air volume flow and felt the wind present at the guest locations. We simulated the wind flow with "STREAM".

4-2 Study of the wind flow

Study of the relative positions of the inlet and the outlet are, as shown in **Figure 8(a) & 8(b)**. In Model 1, a window is arranged at a position frontally facing the entrance, and in Model 2, the window is arranged in a position diagonal to the entrance, as shown in **Figure 8(a) & 8(b)**. In view of the locations of residents and placement of furniture, we decided to model-1 wind flow in a region where there is a bench in front of the bed, as shown in **Figure 8(a) & 8(b)**.

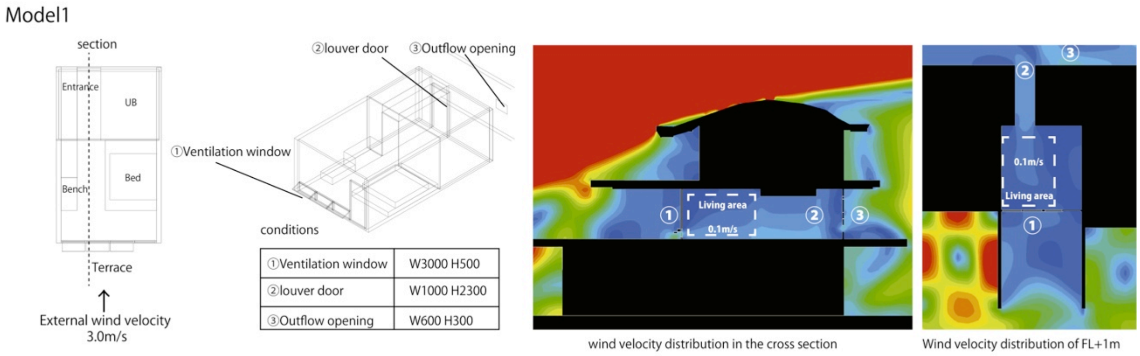


Figure 8 (a) Window layout for Model-1

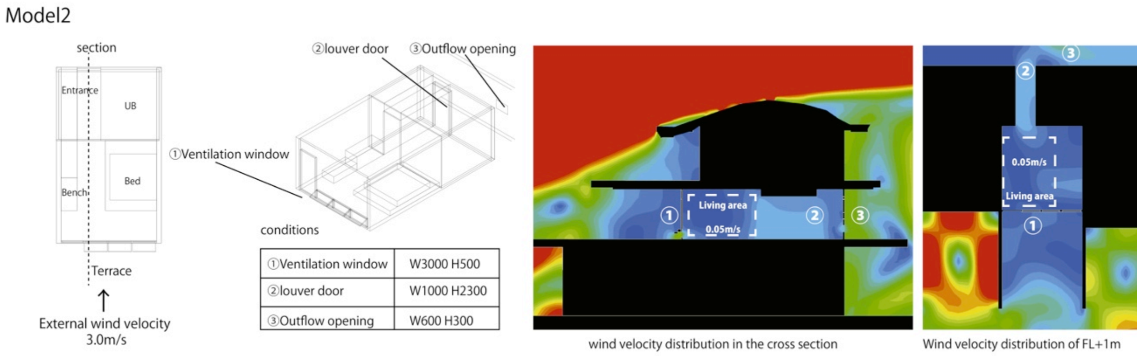


Figure 8 (b) Window layout for Model-2

4-3 Study of the amount of air

In order to easily adjust the air flow, the position and size of the opening of the common corridor was changed, as shown in **Figure 9**. Model 3, as shown in **Figure 9,** is a view after the change. Originally, a window was placed near the ceiling of the front of the entrance door that had been placed randomly, and took larger opening area. As a result of the reconfigured scheme, the wind went from the foot opening, and goes out of the high window, and air volume is increased than Model 1.

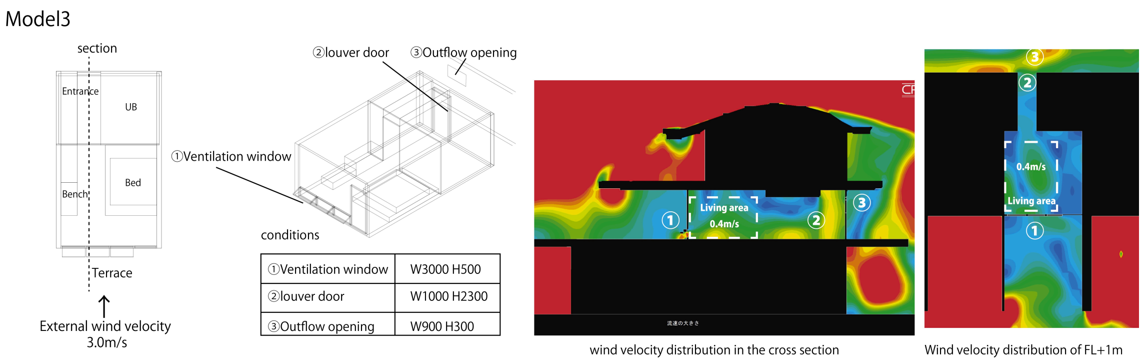


Figure 9 Windows layout for Model-3

4-4 Conclusion

In order to enable the guest to adjust and incorporate their own style, the authors consider how to open the window and placement of the opening, and were able to ensure proper ventilation and air-flow path.

5. CONCLUSION

The building design, based on the above studies, was completed and is currently in operation. The authors consider making comparison between the actual measured value and actual simulations, responsive user praxis of opening the window to introduce outside air, and the feel and experience of hotel guests through questionaire, and the mechanisms of outside air intake. Furthermore, our objective is to advise the hotel management on the low energy practices.

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Session 7A : Passive design

PLEA2014: Day 3, Thursday, December 18
10:25 - 12:05, Auditorium - Knowledge Consortium of Gujarat

From Romance to Performance: Assessing the Impacts of Jali Screens on Energy Savings and Daylighting Quality of Office Buildings in Lahore, Pakistan

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ABSTRACT

Jali Screens are traditional window treatments used in vernacular buildings throughout South Asia and the Middle East. Historically, the screen treatments are successful in providing shade and privacy for building occupants in hot arid and hot humid climates. With interest in traditional building features, recent trends in contemporary buildings design have started to incorporate Jali screens or other screens as decorative façade elements. However, the use of these screens has been widely approached from the aesthetic and romantic attitude representing an architectural fascination with the vernacular. Their impact on overall building energy and daylighting performance, however, has been largely ignored. This paper reports on the results of a multi-methods research project to evaluate the impact of traditional Jali screens with various perforation ratios on energy utilization and daylighting quality in contemporary office buildings in Lahore, Pakistan. The study combined a field assessment of traditional Jali screen performance in historical settings with various geometries and an experimental simulation of the different screen perforations on contemporary offices' energy behavior and daylighting autonomy. The hypothesis studied is that Jali screens with 30%-50% perforations will provide an optimized condition between energy savings and daylighting quality in office buildings. Independent variables including building envelope insulation, shading factor, and perforation percentages of Jali screens were manipulated through different simulation models of an existing office building. The dependent variables in the form of overall energy utilization intensity (kbtu/sf/yr), daylighting autonomy, and annual solar exposure were analysed for the different screen attributes. Simulations, using computational energy modeling, have revealed that Jali screens impact cooling loads and improve visual comfort in office buildings. Moreover, it suggests that designers should look at traditional building strategies from a holistic perspective employing a whole-building approach including aesthetics and an intent to quantify its performance and learn from it without over-romanticizing it.

INTRODUCTION

Lahore, a modern financial center in Pakistan, is dominated with office buildings. These offices are air-conditioned throughout the year. In Pakistan, the current energy crisis makes evaluating building performance an urgent need in design practice. The climate of Lahore is typically characterized by a high intensity of solar radiation. Solar heat gain reduction is of primary concern as a means to reduce energy use and provide comfort to occupants in warm weather (Boake, 2014).

Unprotected glass curtain walls are not very climate friendly in warm and hot-humid Lahore. Typically occupants use blinds on the inside of the window to control glare only, while significantly increasing the total building energy when compared to external shading devices (Moeck et al.). Prior research based on the Lahore region did not use the weather data for Lahore, instead similar climate data was used to draw relevant conclusions. Figure 1 shows a psychrometric chart for Lahore, Pakistan (Source: Climate Consultant 5.5 (B1). While the climate of Lahore is such that comfort is only achieved 15% of the time; an additional 24% comfort time can be achieved through sun protection or shading of windows alone.

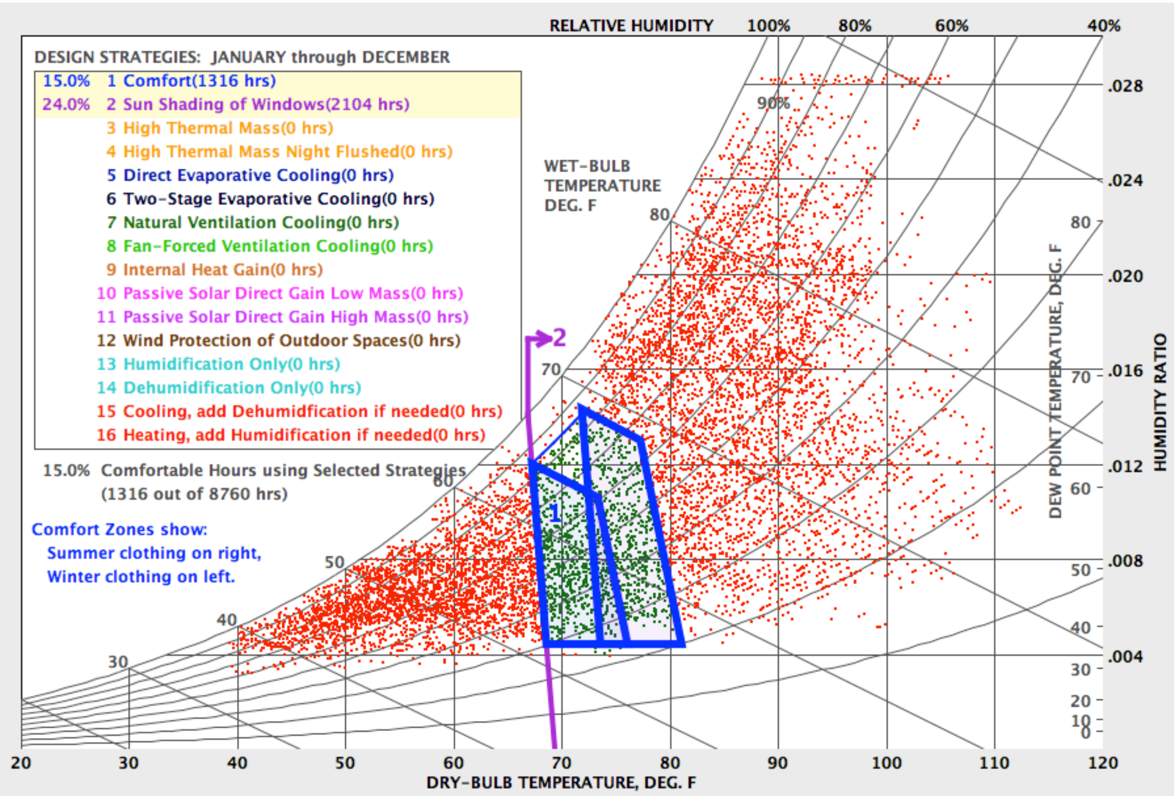

Figure 1. Psychrometric Chart for Lahore, Pakistan (using ASHRAE Handbook of Fundamentals Comfort Model, 2005)

Certain envelope-design strategies have already proved to serve the purpose of energy saving in buildings (Olgyay et al., 1957; Dekay et al., 2014). There are several prescriptive sets of building criteria available to attain the thermal and comfort benefits, and ASHRAE has published several of them (Zhivov et al., 2010). However, such standards pertaining to thermal comfort are not available in Pakistan and the thermal properties of building construction in buildings are very poor. Single glazed curtain wall systems with low thermal resistance envelope designs are still prevalent. A few buildings in the Gulf area and in Pakistan have performance claims, which are not backed by any hard numerical evidence (Boake, 2014).

Jali screen façades have been widely used as vernacular shading devices in the Pakistan, India and Middle Eastern countries. Previous studies have proved their climatic adaptation and environmental performance (Elzeyadi, 1996). Jali, in Urdu language, means a perforation or perforated screen. Over the years, architects and builders have acknowledged its benefits as a screen that filters light and air, while allowing selective privacy. Traditional Jali facades are replicated and used in contemporary buildings in Lahore, Pakistan. However, there is a lack in understanding of their performances in a quantitative manner and unavailability of scientific means that could be used for developing new efficient designs that suit the modern façades of office buildings in Lahore. Figure 2, shows an example of a contemporary building in Lahore where Jali facades are used as ornament and daylight is blocked out. Fathy (1986) indicated that perforated screens, for example Mashrabiya in Egypt (Fig. 3) affect the quality of space and improve visual comfort in spaces by reducing glare. Several studies show that external screens reduce solar penetration as solar radiation is rejected before hitting the glazing (IESNA Lighting Handbook 2013; Kwok et al., 2011). The hypothesis of this study was that Jali Facades in Lahore would help achieve thermal comfort and as well as improve daylighting performance in office environments.


Figure 2. Mall of Lahore (left) is a commercial building with ornamental Jali Facades, Lahore (Source: author); Figure 3. The House of Suhaymi (right) in Cairo, with one of the Mashrabiyas, Egypt (Source: Wikipedia accessed on September 16, 2014).

Research Setting - Traditional vs. Contemporary

Three Jali screens were selected from typical vernacular architecture of Lahore. The Lahore Fort has the largest collection of Jali screens in place from the Mughal times (16^{th} to 19^{th} century). All three cases selected for investigation are west facing with a perfortation ratio of 30%, 40% and 50%. Perforation ratio, for this study, is defined as the ratio of void to solid area of a screen. The depth of screen was fairly constant at 0.25’ (3 inches) and after an analysis of screen geometry (Fig. 6) the depth to width ratio of 1:1 was taken as most commonly occurring.

A typical office building was selected to act as the contemporary research setting. This base case building was located in the Commercial Area of Y-Block, Defence Housing Society in Lahore, Pakistan. This building is at the corner junction of two main roads with facades facing South and West composed of single pane unprotected glazing. It consists of 5 floors including Basement, Ground, Mezzanine, First, and Second typical floors (Fig. 4). For detailed daylighting analysis two rooms on the Second floor are selected as shown in Figure 4. Information on building characteristics such as location, orientation, environmental factors, envelope characteristics, installation systems, comfort ranges, schedules, and occupancy were gathered (Caccavelli, 2000; Butala, 1999; Gücyeter et al., 2012). A total building energy audit was acquired for the whole year and readings for daylighting measurements were taken at a 3’ (three feet) grid on working plane for the two offices at morning and afternoon time, on a typical sunny day in April.

RESEARCH METHODS

The impact of Jali screens on energy conservation and visual comfort of typical contemporary office buildings in Lahore, Pakistan formed the core of this investigation. Details of variables, which affect the energy of building, cooling and lighting, were identified and formed the sub-questions of the study and a review of the literature. The results from the field study impacted decisions taken during the experimental design stage. Figure 5 describes the parameters used in the experimental desgn stage. In order to simulate conditions accurately, this research employs dynamic energy simulation, starting with a building audit of the existing base case scenario, which was then fed into the simulation model to assess existing performance levels and create a calibrated model. Figure 5 shows the flow of methods employed for this research.

Figure 4. Contemporary Research Setting: West Façade (left); South façade (right).

Computational and environmental simulation software, IES Virtual Environment Pro (IES_VE), program used in this experimental research (Kim et al., 2012) and has been verified in many publications (The American Institute of Architects, 2012; Elzeyadi, 2009). Only four modules of the package were used to carry out this investigation, which are “ModelIT”, “SunCast” for solar shading analysis, “Radiance” for dynamic lighting simulation and “Apache Sim” for thermal simulation (Muhaisen, 2006; Aldossary, 2014).

Next, Jali screens defined from the traditional research setting (traditional building cases) and designed for this experiment were tested through the calibrated model. The calibrated model was further validated with Target finder and the EUI values in the base case were found to be too high for a balanced experiment. High performance thermal constructions were employed and verified as having a significant impact on performance. Furthermore, all shading devices were based on the optimized base case model (Fig. 5).

Envelope design in Lahore is very leaky and has low R-value. High performance buildings require not only good shading design but also thermal constructions with higher R-values. Research has shown that with bad thermal construction and leaky envelopes, shading devices cannot achieve the same effect as a good thermal construction (Sourced from GCT High Performance Template) (Elzeyadi, 2008). High performance materials were used for further final simulation for testing all shading devices (Table 1).

Table 1. High Performance Thermal Constructions used in Simulation Model

Roof	High Performance Roof [R40]
External Wall	High Performance Wall [R-30]
External Glazing	Low-e Triple Glazed [R-5]
Ground Floor	Super Insulated Floor [R-25]

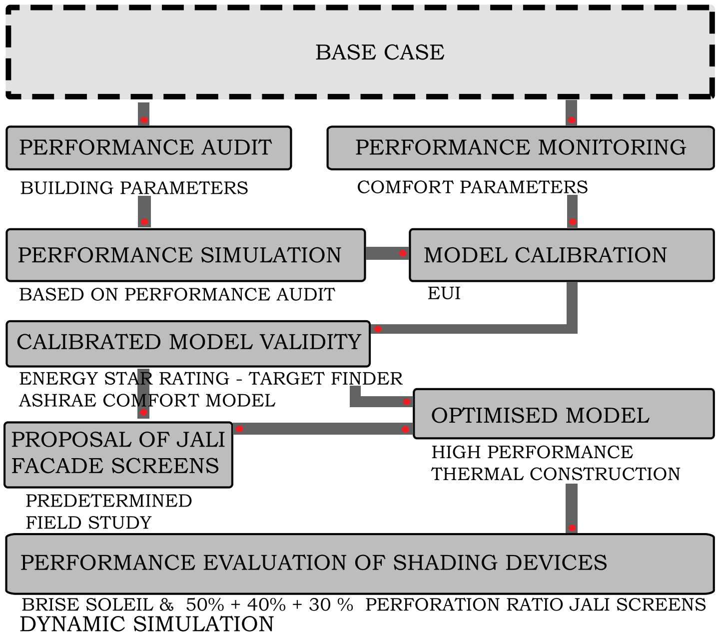

Figure 5. Flow Chart of Performance Monitoring, Calibration and Optimization

Further optimization was achieved through the use of dimming profile for lighting controls (High performance Template) (Elzeyadi, 2008). According to this template, a value of 360 lux was set on the work surface to optimize lighting controls such that maximum utilization of daylighting was achieved and electric lighting minimized during an ASHRAE work day of 8:00 am till 6:00 pm. Figure 5 shows the process through which the simulation model was calibrated and optimized to achieve the best results for assessment of Jali screen façades.

Jali patterns were investigated and derived in the traditional research settings. It was found that most shapes were derived from a hexagon in the Jali screens (Fig. 6). In order to simplify the process, therefore, basic shape of a hexagon was selected for the purpose of experiment. To find a screen configuration of highest energy saving potential, a range of solar screen designs was examined by performing computer simulation using IES VE dynamic simulation software.

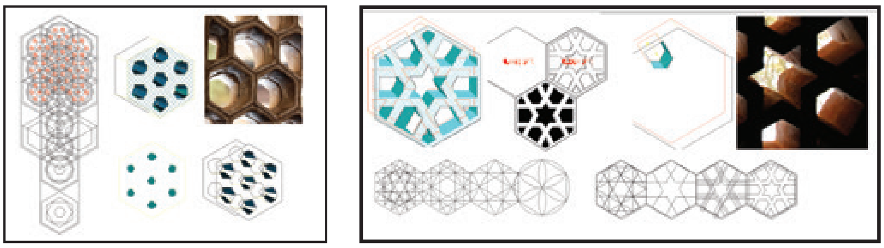

Figure 6. Jali Geometry Detail

ANALYSIS

Energy Performance and Thermal Comfort

Initial data collection from base case contemporary building indicated that the temperatures were out of comfort range. Both diagrams (Fig. 7) show how the temperature recorded in the study rooms was found to be out of the comfort zone defined by ASHRAE 2005 Comfort Model (Climate Consultant 5.5 B1) and Center for the Built Environment: CBE Thermal Comfort Tool.

To account for building energy consumption, Energy Utilization Index (EUI) was used to compare the energy benchmarking of building and design strategies. Mean EUI of commercial buildings in the US was calculated from Target Finder and used to compare with the base case EUI in Lahore (Fig. 8). EPA's online Target Finder Calculator (EnergyStar) was used to find the base case building Site EUI for a similar climate zone in the US. Target finder US Base case was 77 kBtu/ft^2/yr and the value of existing building is calculated at 254 kBtu/ft^2/yr.

The base case contemporary building was then modeled with the existing construction techniques in the building as built in Lahore, Pakistan. The results of this simulation showed a high value of 80.3 kBtu/ft^2/yr. When using better construction, i.e., using GCT High Performance template, as shown in Table 1, studies have shown significant impact on the energy performance of buildings (Elzeyadi, 2008). Introducing better thermal construction reduced the EUI to 67.68 kBtu/ft^2/yr. Furthermore; the existing conditions of base case were not optimized for lighting and solar gain. By introducing a dimming profile of ASHRAE 8:00 am – 6:00 pm workday, the EUI was further reduced to 55.01 kBtu/ft^2/yr (Figure 9).

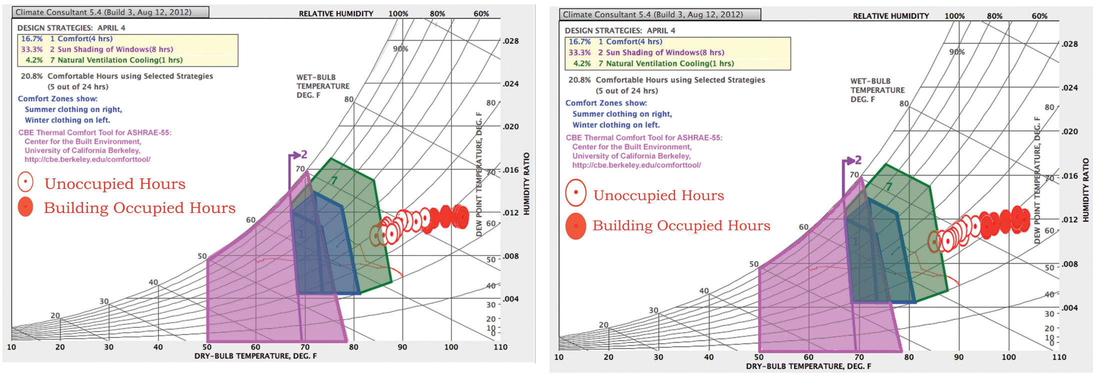

Figure 7. Psychrometric Chart (South - left) (West - right)

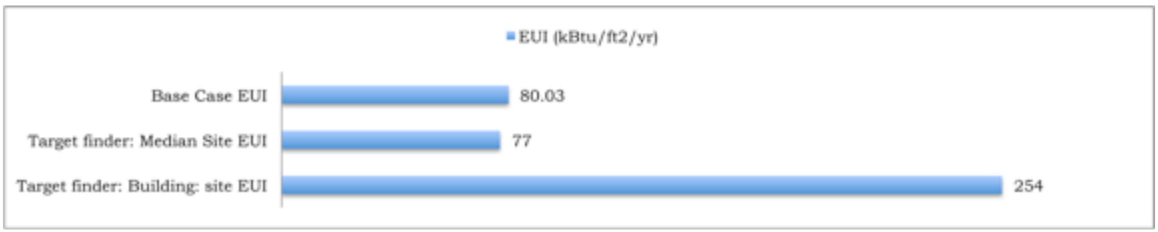

Figure 8. Building EUI comparison with Energy Star Rating

External shading devices, three types of Jali screens, were then added to this computational building model. As shown in Figure 10, EUI improved with perforation ratio of 30% to 50%, with 50% Jali perforation screen as the best performer due to combination of solar heat reduction and daylighting potential.

Figure 9. EUI Values derived through Dynamic Simulation Modelling

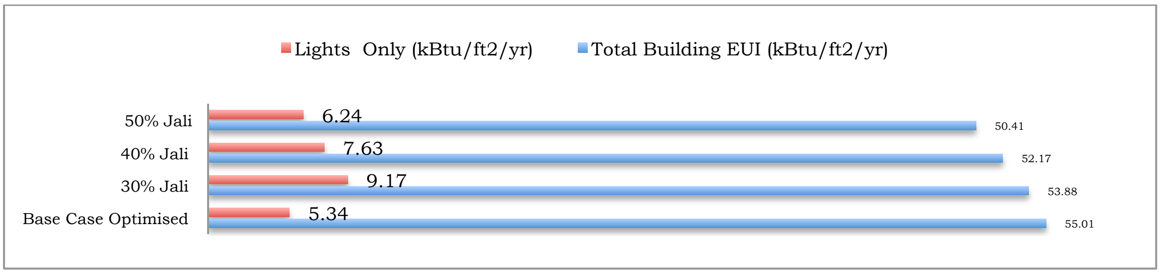

Figure 10. Comparison of Lights Energy and Total Building EUI

Daylight Performance

Experiments for the previous simulations were conducted in Radiance module of IES VE dynamic simulation software. The times of the day were set to the 8:00 am to 6:00 pm workday, per IES standard a given preset in IES VE dynamic simulation software. The reference plane on which daylighting performance was simulated contained sensors at a height of three feet above floor (working plane). Dynamic daylight performance metrics were used to assess the illuminance ratios within the rooms. These simulations extended over the whole calendar year and were based on external, annual solar radiation data for the building site. The key advantage of "dynamic daylight performance metrics compared to static metrics is that they consider the quantity and character of climate and seasonal variations of daylight for a given building site together with irregular meteorological events" (Reinhart et al. 2006). Two metrics used in this research were Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) both defined by IESNA (IESNA Lighting Handbook) and found most suited for assessing daylighting quality in an office environment and solar penetration through the Jali screens.

South Orientation

When assessing through the Spatial Daylight Autonomy (sDA) metric, all shading strategies fulfilled the criteria of being 100% as shown in Figure 10 (Green – pass; red – no pass). There was sufficient daylighting to fulfill the minimum daylighting criteria. However, Annual Sunlight Exposure metric was not fulfilled barely towards the back of the room in 30% Jali perforation ratio. It is predictable due to the lesser lighter penetrating deeper on South. This indicated further shading in the deeper parts of the building.

West Orientation

In the west room, the Spatial Daylight Autonomy (sDA) could not be achieved in lower perforation ratios. For the optimum lighting requirement, dependence on electrical lighting increased, while impacting lighting energy (Fig. 10). Similarly in Annual Sunlight Exposure metric, 50% Jali perforation received maximum amount of direct beams of sunlight in comparison to lower perforation ratios (Fig.

11).

Discussion

Energy was measured and assessed in the EUI metric (Fig. 9 & Fig. 10). The thermal construction of a building had a large impact on its energy performance. This study showed that by optimizing the thermal construction using Green Class Toolbox (Elzeyadi, 2008) high total energy savings were made possible. Earlier, it had been discovered during field research, that thermal consrtuctions of buildings in Lahore is not up to ASHRAE standard. Installing standardized construction by using thermal and vapour barriers in building envelope should dramatically improve performance of buildings (Fig. 9). Solar shading devices on windows are significant components of vernacular building façades in Lahore, Pakistan. This research showed (Fig. 10) how each of the three Jali screen façades affected the total energy of the building. Out of the three screen geometries, it can be concluded from this study that the 50% perforation ratio performed best (1:1 perforation to depth). As the perforation ratio was increased from 30% to 50% whole building energy performance improved due to decreased reliance on on electrical lighting for daylighting (Fig. 10 & Fig. 11). In comparison, 50% Jali perforation was the better option for a balanced energy approach to provide thermal comfort and provide optimum daylighting. The impact of Jali screen geometry on energy performance is significant to suggest that designers may use this research to improve thermal visual comfort in contemporary buildings and reduce depence on electricity.

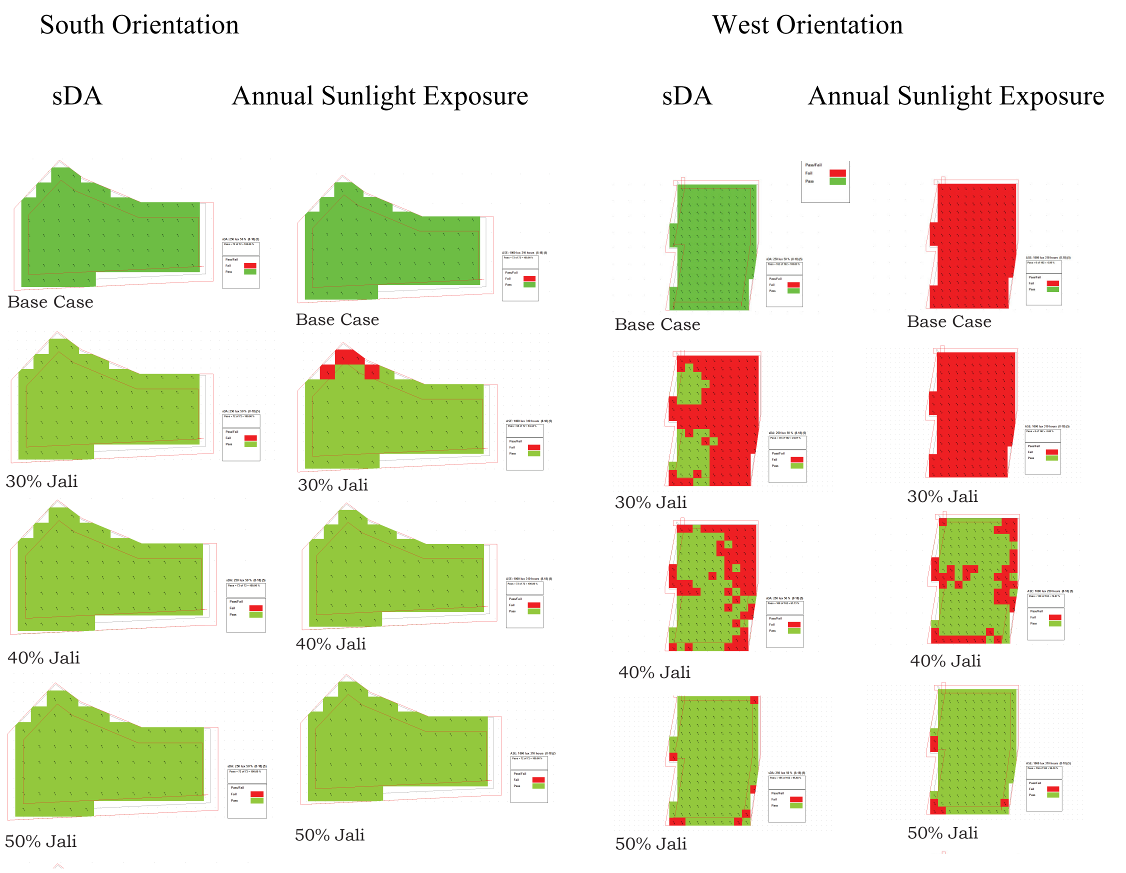

Figure 11. South Orientation (left) Spatial Daylight Autonomy: (left) and . Annual Sunlight Exposure (right); West Orientation (right) Spatial Daylight Autonomy: (left) and . Annual Sunlight Exposure (right).

CONCLUSION

This research examined the effect of Jali Screen façades on the year round energy performance and daylight performance through a dynamic simulation model. The conclusion is focused on the impact of shading devices beyond the aesthetic application; in particular, the geometry of Jali screens façades on Energy Saving and Daylighting Performance in contemporary office spaces in Lahore, Pakistan. For each of the two orientations, South and West, three Jali screens were designed and simulated. In order to draw a conclusion from this study, a holistic approach towards cooling and lighting energy is required, using a whole building design approach. While implementating Jali screens in contemporary façades, designers may seek aesthetic quality along with thermal and visual comfort. Masterbuilders had embedded this information in the various screens found in the traditional architecture of Pakistan, especially Lahore, and we can re-learn from these façade systems to develop a high-performance building design. Jali screens can be optimized for beauty and performance given the parameters are carefully designed.

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Concept, Design and Performance of a Shape Variable Mashrabiya as a Shading and Daylighting System for Arid Climates

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ABSTRACT

The design of a solar protection system that can minimize solar gains while maximizing daylight and view to the outside is particularly challenging in arid climates, such as in the Middle-East, where sand, wind and corrosion impose specific constraints. We propose a system that provides a trade-off for three requirements: (i) maximize diffuse sunlight and view to the outside, (ii) efficiently block direct sunlight and (iii) transform a fraction of it into diffuse light for indoor daylighting. Compliance with this last requirement provides a solution for the common problem of insufficient daylighting even in the presence of abundant solar radiation, which often forces occupants to fully close their shading system and use electric lighting. In addition, our design potentially copes well with these extreme environmental conditions and preserves local architectural character (mashrabiya-inspired design). In this paper, we establish quantitative specifications for these three requirements, provide the working principle of our shading and daylighting system and its design, which consists of a shape variable mashrabiya (SVM). We calculate and analyze the annual daylighting performance of our SVM and benchmark it against the performance of Venetian blinds and diffuse sunlight alone. Finally, we provide the minimum reflectance required for the SVM to comply with our third requirement. We built a mock-up of our SVM to investigate the validity of our simulation model.

INTRODUCTION

The abundance of solar radiation in arid regions like in the Middle-East requires a very efficient shading system, in particular when aiming to provide visual comfort and prevent excessive solar gains. In addition, the combination of sand, wind and corrosion due to prevalent condensation creates harsh environmental constraints. On the one hand, the static vernacular solution named mashrabiya (perforated shield with oriental motifs) is well adapted to these constraints but fails to meet our contemporary needs for visual comfort due to insufficient daylighting and view to the outside. On the other hand, a kinetic shading system like Venetian blinds meets the requirements for efficient shading and for visual comfort (minimal glare, adequate daylighting and maximum view to the outside). However, to avoid excessive solar gains, such a shading system must be placed outside of the window, where it cannot withstand the harsh local environmental conditions. More sophisticated contemporary technologies embedded in the window, like electrochromic glass, are in principle unsuitable for these climates due to their propensity to absorb solar radiation resulting in excessive solar gains. Therefore, the challenge is to design a kinetic shading system that can cope with these harsh environmental conditions.

We propose a solution relying on a simple strategy to deal with abundant solar radiation that is applicable in these specific climatic conditions. With clear sky conditions prevailing throughout most of the year in these regions, strong direct sunlight on a window must be blocked without compromise. We believe that fine adjustments of the shading system with solar incidence angle are not strictly necessary, and not even desirable when striving to minimize solar gains. With this assumption, the shading system is closed in the presence of direct sunlight, and open when diffuse sunlight dominates. The sufficiency of such a binary function facilitates the design of a simple and robust kinetic shading system with the potential to cope with harsh climate conditions. Another important motivation for using a kinetic shading system with binary operation is the possibility to obtain a solar responsive system by exploiting a novel passive actuator. Applied as such, our approach would provide insufficient daylighting when blocking direct sunlight. This limitation, which is commonplace - independently of climatic conditions - in most shading systems, quite absurdly forces the occupants to use electric lighting despite abundant daylight availability. To tackle this, we devised a shading system that allows blocking direct sunlight while transforming a sufficient fraction of it into diffuse light for indoor daylighting. In addition to this key design-goal, we will devise a system that aims to preserve local architectural character.

In this paper, we provide the high-level requirements for this shading/daylighting system and explain its working principle. Then, we establish more detailed specifications and present the resulting design. We investigate the minimal reflectance required for the system to meet our daylighting goals and calculate annual daylighting performance. We close with a discussion of our results and benefits of this novel customized solar protection for arid climates.

SHADING AND DAYLIGHTING SYSTEM

High-level requirements

Our shading and daylighting system must comply with the following technological, functional, and architectural requirements: 1) ability to switch in a timely manner between an open and a closed configuration, in the absence and presence of direct sunlight, respectively; 2) maximal daylighting and view to the outside in the open configuration; 3) efficient shading and minimal solar gains in the closed configuration; 4) transformation of a sufficient fraction of the blocked incident direct sunlight into diffuse indoor daylight; 5) ability to withstand the harsh local climatic conditions; 6) potential for coupling our solar responsive system; 7) preservation of some local architectural character by using a mashrabiya-inspired design in both the open and close configurations. To reflect the above requirements, we will designate our system by “shape variable mashrabiya”, abbreviated SVM.

Concept and working principle

Our SVM is made of three identical perforated opaque shields that can move relative to each other to switch between an open and a closed configuration (**Figure 1**). A shield consists of a bi-dimensional assembly of identical perforated motifs, each covering a square area with side-length ℓ.

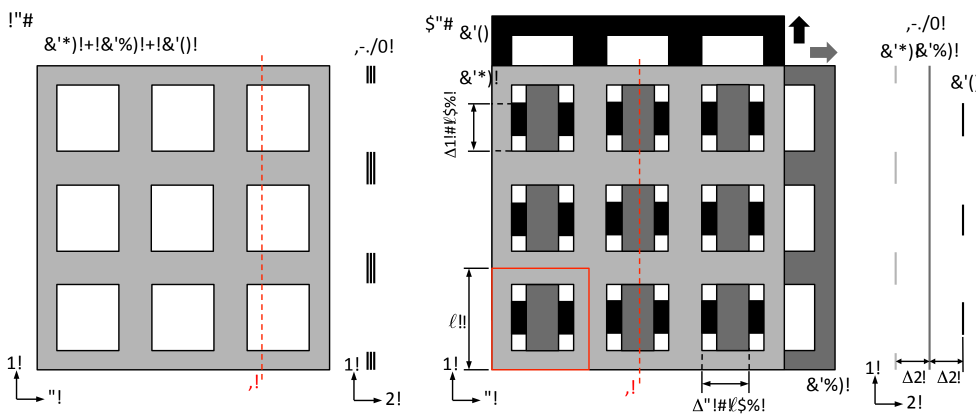

Figure 1 Concept and working principle of the SVM. (a) Open configuration. (b) Closed configuration.

The first shield is always motionless. In the open configuration (**Figure 1 (a)**), used when diffuse sunlight dominates, the shields are exactly superimposed and nearly in contact with each other. In the closed configuration (**Figure 1 (b)**), activated in the presence of direct sunlight, the second (S2) and third (S3) shields individually move along the vertical and lateral dimensions (x- and y-axis) by half of the motif length ($\ell/2$), respectively. Moreover, they both move in the z dimension to create a gap of length Δz between the shields, whose role is to allow multiple scattering reflections. As illustrated in **figure 2 (a)**), with an appropriate design, this results in the transformation of a significant fraction of direct sunlight into scattered light. Such a direct into diffuse light transformation (DDT) function must be optimized to obtain sufficient diffuse indoor daylighting.

To simultaneously move a shield along the lateral (x or y) and axial (z) dimensions, we devised a mechanism requiring few components and minimizing friction. It consists of a simple parallelepiped mechanical structure that allows switching between the two configurations by rotating the structure of an angle (γ), as depicted in **figure 2 (c)**. This structure allows simultaneously moving a whole assembly of mechanically interconnected shields from a single rotation point (P).

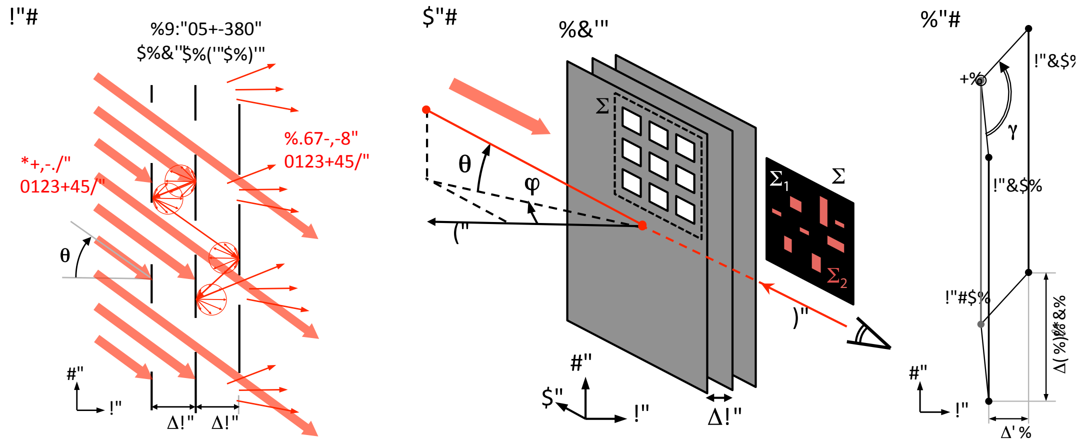

Figure 2 (a) Concept of the direct to diffuse light transformation (DDT) function. (b) Key geometrical parameters for defining the Shading Efficiency Factor (Γ), used in our specifications. (c) Mechanical concept for moving the SVM shields.

We plan to produce the required mechanical couple by means of a solar passive actuation and detection system based on a combination of custom optics and phase change material, which is currently being designed in our group. Such a solar responsive system, which is essentially restricted to binary actuation, lends itself well to moving our SVM. Since solar irradiation decreases with the cosine of incidence angle, solar gains are significantly reduced at elevation angles above 60°. Glare issues generally also become less critical in this angular range. Therefore, we designed our solar responsive system to switch from open to closed configuration at angles for $\theta < 60°$ and $|\varphi| < 60°$ (**Figure 2 (b)**).

The combination of such a simple solar responsive system (no detector, motor, electronics), whose description is outside of the scope of this paper, with this simple mechanical structure, is key to obtain a robust enough system potentially able to cope with the harsh local climatic conditions.

SPECIFICATIONS AND DESIGN OF OUR SHAPE VARIABLE MASHRABIYA (SVM)

Specifications

Shading. Specifications for shading depend on performance objectives, which are related to climate and to the usage of the space considered. Therefore, shading specifications are largely case-dependent. Here, we consider a public space (lobby, hall etc.) located in arid regions, for which glare and solar gains must be minimized. Such an objective can be formulated by means of a quantitative requirement on the maximum fraction of direct sunlight traversing the SVM structure. In the open configuration, since all three shields are superimposed, we simply need to specify the shading ratio (complement of the perforation ratio) of a shield of the SVM. Since, in the closed configuration, the shading ratio depends on the viewing direction (v), it is defined as: $\Sigma_1/\Sigma = (\Sigma_2 - \Sigma)/\Sigma$, where Σ_2 and Σ_1 are the illuminated and shaded surface portions of an area Σ (see **figure 2 (b)**). To establish a specification we need to introduce a more complex metric that accounts for this angular dependence of shading. We define the shading efficiency factor (Γ) as a percentage corresponding to the average shading ratio (μ) minus the standard deviation of this shading ratio (σ) for all viewing angles to be considered in the closed configuration, i.e. for $\theta < 60°$ and $|\varphi| < 60°$ (see above). Assuming a Gaussian distribution of these angular shading ratios, subtracting σ implies that the probability to have angular shading ratios lower than a specified Γ is of about 15%.

Based on these considerations and definitions, we establish, somewhat arbitrarily, the following two specifications with which our SVM must comply to best meet our high-level requirements #2 and #3:

A. In its open configuration, the shading ratio must be lower than 50%.
B. In its closed configuration, for $\theta < 60°$ and $|\varphi| < 60°$, one must have: $\Gamma > 90\%$

Direct into diffuse light transformation function (DDT). The DDT function efficiency (η) of the SVM is the ratio of direct sunlight transformed into diffuse light to the incoming direct sunlight in the closed configuration. Our specification for η is based on a benchmark and can be expressed as follows:

C. The DDT function of the SVM must provide daylighting at least equivalent to that provided by diffuse sunlight without a shading system (benchmark), throughout a whole typical meteorological year across the entire specific space considered.

Mechanical requirements. To reduce complexity and cost, no more than three shields must be used. To allow a simple and robust movement between the open and close configurations, as well as mechanical compliance with our passive actuation system, the mashrabiya shields S2 and S3 must move laterally (x-dimension) and vertically (y-dimension), respectively. Diagonal motions are not allowed.

Design and results

The final design of our SVM is the result of a trade-off between the mechanical and optical (A,B,C) specifications established above, while aiming for a mashrabiya-inspired design. Compliance with our mechanical specifications (three shields and orthogonal motions) is not easy to obtain given the conflicting specifications on shading for the open and the close configurations (max. shading ratio *versus* max. shading efficiency factor), in particular with the requirement of having a distance between the shield (Δz) and a mashrabiya-inspired design. Moreover, the shading efficiency factor (Γ), which must be maximized to meet the requirement for the closed configuration, decreases with the inter-shield distance Δz, while the DDT function efficiency increases with Δz, as explained later. What further complicates the design is that Γ does not vary as a function of Δz in a predictable manner because of the relatively complex geometry of the mashrabiya-inspired shield.

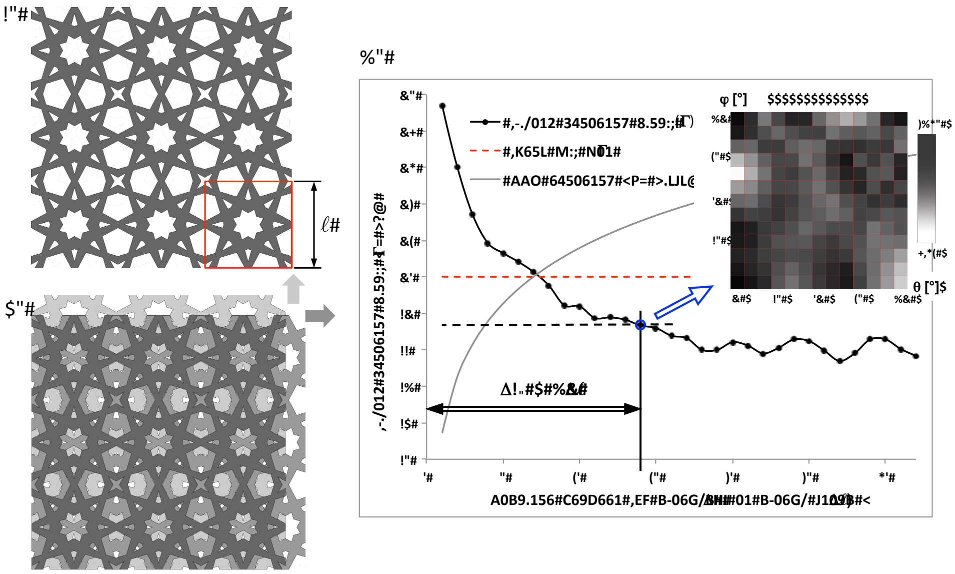

Figure 3 Resulting SVM design in (a) open configuration, and (b) closed configuration. (c) Plot of shading efficiency factor (Γ) and DDT function efficiency (η) against Δz, expressed in shield units $\Delta\ell = \ell/64$. Onset: Angular distribution of shading ratio at design trade-off distance $\Delta z_d = 14\Delta\ell$.

For our design, we used an iterative procedure with sequential calculations of Γ as a function of

Δz for different shield geometries till we found a viable trade-off. To get fast calculations of $\Gamma(\Delta z)$, we created a code in Grasshopper that calculates the shading ratio for all combinations of θ and φ angles varying in steps of 5° within the angular range ($\theta < 60°$ and $\varphi < 60°$), i.e., 169 combinations. The best trade-off we obtained led to the shield geometry shown in **figure 3 (a)**. The corresponding closed configuration is shown in **figure 3 (b)**. With this trade-off, we obtained a shading ratio of 54.1% and a shading efficiency factor of 88.7%, both values out of specifications (<50% and >90%, respectively). **Figure 3 (c)** shows the room for trade-off in the closed configuration between the variables Γ and η with conflicting trends.

Figure 3 (c) shows the plot of the DDT function efficiency $\eta(\Delta z)$, which corresponds to a fit across values calculated further in this paper. As shown in this figure, η increases with Δz with a horizontal asymptotic behavior while Γ, calculated with our Grasshopper code, decreases with Δz in a similar way. The distance Δz is expressed in a dimensionless unit corresponding to a fraction of the shield length motif (ℓ), which is $\Delta\ell = \ell/64$ (arbitrary choice). We used this unit because Δz ultimately only depends on the motif length, which is *a priori* unknown and remains a free design parameter (see below). In principle, to meet our specs for Γ, Δz must be smaller than $8\Delta\ell$ (**figure 3(c)**). For our trade-off, we preferred to have higher η at the expense of an only marginally lower Γ (88.7%) corresponding to $\Delta z_d = 14\Delta\ell$, which is the inter-shield distance used in our design. The **onset of figure 3 (c)** provides quantitative insights into the shading ratio versus the angle of view (θ and φ) at Δz_d.

Our design procedure has provided the shape of the shield and the relative size of the SVM structure ($\Delta z_d/\ell$). The absolute size of the SVM, i.e. $\Delta\ell$, and in turn Δz_d, was determined by a subjective appreciation of the most suitable scale of our SVM for best acceptability in its open configuration, with respect to interference with view to the outside and visual aspect in a room. To this aim, we carried out a brief survey based on a real-scale mock-up and computer rendering simulations. This resulted in a general consensus that a suitable motif size (ℓ) is of the order of ℓ = 16 cm. This value yields an amplitude of displacement $\Delta x = \Delta y = \ell/2$ = 8 cm and a distance $\Delta z_d = 14\ \Delta\ell = 14\ \ell/64$ = 3.5 cm.

DAYLIGHTING PERFORMANCE

To gain quantitative insights into indoor daylighting with our SVM, we need to evaluate the annual daylighting performance in a relevant case-study. Another specific goal is to determine whether our SVM - in its closed configuration - allows comparable or superior illumination than that provided by diffuse sunlight. First, we need to optimize the DDT function of our SVM.

Optimization of DDT function

The DDT function efficiency (η) of the SVM, i.e., the ratio of direct sunlight transformed into diffuse light to the incoming direct sunlight, mainly depends on three parameters: the angular intensity scattering distribution of the shield material - characterized by the "specularity" parameter (S) in RADIANCE, the distance between the shields (Δz), and the reflectance of the shield material (R).

To investigate the first two parameters (S and Δz), we opted for a brief sensitivity analysis by means of "point-in-time" simulations with the software DIVA-for-Rhino, which exploits RADIANCE algorithms. Light scattered by the SVM was measured as a function of S and Δz at a location free from any direct sunlight contribution (ceiling). First, the parameter S was varied in five equal steps of 0.2 between a Lambertian and a much more specular intensity scattering distribution (S = 0.1 and S = 0.9 in RADIANCE, respectively). Quite surprisingly, the simulations revealed that η is nearly independent of specularity. The parameter Δz was then increased in five even steps between $\Delta z = \ell/10$ to $\Delta z = \ell/2$ = 8 cm. The simulation results revealed that η increases with Δz with a horizontal asymptotic trend. As shown earlier, this is the specification on Γ that sets a limit on η leading to the optimal trade-off distance of Δz_d = 3.5 cm. Due to lack of space, we do not provide all the details of this sensitivity analysis.

Given that η obviously increases with reflectance, such an analysis is not required for this parameter. However, since the maximum reflectance value is practically limited by the availability of suitable materials and by ageing - especially when exposed to outdoor conditions - it is essential to determine the minimum value for R that allows for compliance with our specifications on η (see above). One option to find the minimal R would be to carry out a sensitivity analysis by means of annual daylighting simulations. However, since these simulations are very time consuming (around eight days) with the available computer resources, and are thus impractical for such a sensitivity analysis, we opted for getting a rough estimate of the minimum R required using the method described below.

Determination of minimum reflectance: method and results. Our goal is to find out what is the minimal reflectance of our SVM that provides, in closed configuration, an illumination just superior to that provided by diffuse sunlight without any solar protection. Since our SVM is meant to be used in arid climates, we chose to carry out our investigation for Abu Dhabi (latitude 24.47°). Our method relies on point-in-time simulations with average values representative of the typical climate that prevails at this location. Calculation of the average diffuse sunlight - which corresponds to our benchmark - is based on the yearly average of all data for diffuse horizontal irradiance (between sunrise and sunset) provided in typical meteorological year (TMY) files. For Abu Dhabi this value was found to be equal to 130 W/m^2. In a similar fashion, calculation of direct average sunlight illumination was based on the yearly average of all TMY data for direct horizontal irradiance with elevation and azimuth angles falling in the angular range corresponding to the closed SVM (same range as used for the calculation of Γ). We found a value of 479 W/m^2, which is used in our simulations at the mean angle of the range considered, i.e., at an elevation angle of 30°. Our calculations, which are performed with the Perez sky model in DIVA-for-Rhino, account for both the direct and the diffuse sunlight contributions.

Our simulation model consists of a rectangular volume with a square side covered by our SVM. We use one millimeter thick shields made of ten by ten motifs, corresponding to a size of 160 by 160 cm². To avoid direct sunlight, we calculated the illuminance as a function of the distance for the SVM (I(z)) along an axis centered on the ceiling-wall of our space, which is delimited by fully absorbing walls. The material of the shields had Lambertian scattering properties (S = 0, in RADIANCE).

Results and analysis. The results of our sensitivity analysis for the reflectance, obtained with point-in-time simulations using the method described above, are shown in **figure 4 (a)**. The illuminance I(z) calculated on the ceiling measurement axis is plotted for a few reflectance values (R=0.5, R=0.7, R=0.8, R=0.9) against our benchmark corresponding to yearly average diffuse sunlight in Abu Dhabi. These plots correspond to exponential fits through average illuminance values calculated at forty evenly spaced sensors along the ceiling measurement axis, which is approximately 210 cm long.

These results suggest that a reflectance larger than R = 0.7 gives an indoor illuminance slightly larger than that obtained with average diffuse sunlight conditions. Compliance with this key specification for R is demanding but still practically attainable with widespread materials.

Our relatively simple method can only provide rough figures for the benchmark and reflectance plots. Indeed, our point-in-time simulations are based on average quantities for diffuse and direct sunlight, and on a single average incidence angle for the latter. Moreover, we need to account for both spatial and temporal distribution of illuminance on the whole measurement plane. Annual daylighting simulations can provide more comprehensive and reliable figures, and improve our estimate of R.

Annual daylighting performance

Method. For the annual daylighting simulations, we considered a standard room with a West-facing glass wall. We analyzed and compared the annual daylighting performance obtained for three cases: a double pane glass wall without shading system, standard Venetian blinds and our SVM. The Venetian blinds are mounted on a double pane glass wall with 65% transmission, whereas the SVM in mounted on a double pane glass with low-E coating yielding 80% transmission. The room has a depth, width and height of 5 m, 3.52 m and 3.04 m, respectively. The sensor plane lies at a height of 85 cm with a clearance of 60 cm from the walls. This yields a sensor plane of 2.32 m x 3.8 m, which was divided into a grid of 160 sensors, each measuring 23.2 x 23.75 cm. The floor, walls, and ceiling were modeled as Lambertian scattering surfaces with a reflectance of 0.3, 0.65 and 0.8, respectively. The SVM shields have a reflectance R = 0.8 and Lambertian scattering properties. The configuration of the SVM, as well as the orientation of the Venetian blinds, are determined by the angle of incidence of direct sunlight according to the acceptance angle specified for our solar responsive actuation system (see above).

For our calculations with the Venetian blinds, we used the same simplified model as implemented in the DAYSIM interface, in which three tilt angles (β) of the blinds are determined by the solar incidence angle (θ) depending on specific angular thresholds. We used $\beta = 0°$ for $\theta < 15°$, $\beta = 30°$ for $15° < \theta < 30°$, and $\beta = 60°$ for $30° < \theta < 90°$, where β is taken relative to the window surface. This model uses standardized occupants behaviors. In the so-called "passive" behavior used here, the occupant leaves the blinds in their horizontal position ($\beta = 90°$) for long times dominated by diffuse sunlight (e.g. in the morning for a West-oriented façade). An algorithm, which we wrote in Python, was used to determine the moments throughout a typical year (8760 hours) corresponding to the specific angles that determine the sequence of actuation for either shading systems considered (SVM and blinds). The illuminances corresponding to this sequence, which are calculated by DIVA-for-Rhino with the Perez sky model, are used for the calculation of temporal maps.

Results and analysis. Temporal maps are used to present the results of our annual daylighting performance simulations obtained for a double pane glass wall without shading system, with standard Venetian blinds, and with our SVM made of shields with reflectance R = 0.8 (**Figure 4 (b)**). The triangular color scale allows showing the Acceptable Illuminance Extent (AIE), introduced by [Kleindeinst *et* al. 2012] to provide a visual representation of the fraction of our sensor grid that is above, below or within the illuminance range considered. Our range, which we call useful daylight illuminance autonomous (UDI-a), following Marjalevic's definition, is defined by bottom and top boundaries of 500 and 3000 lux (sharp cut-offs), respectively [Mardjalevic, 2009].

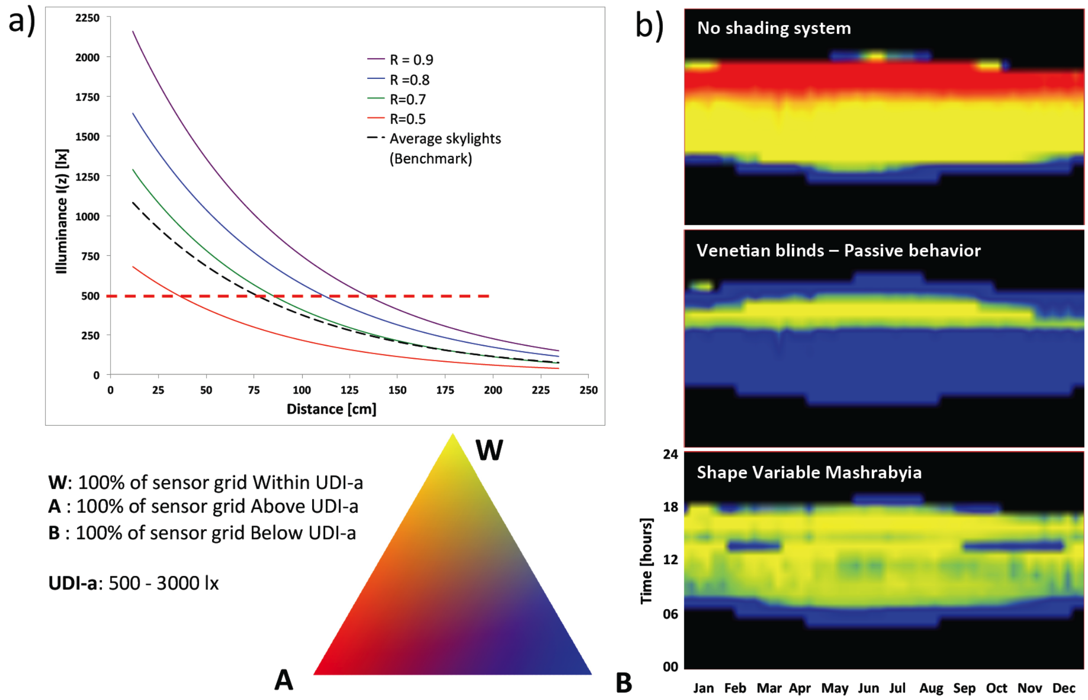

Figure 4 Annual daylighting performance for a West-facing room. (a) Average-based point-in-time simulations for closed SVM. (b) Temporal maps for three cases, including closed SVM with shield reflectance R = 0.8. Triangular color scale allows showing spatial intensity distributions.

Without a shading system, illuminance exceeds our high boundary of 3000 lux nearly all afternoon-times (solar noon to sunset) for most of space, as expected for a West-orientation. During morning-times (sunrise to solar noon), illuminance falls within the UDI-a boundaries (500 – 3000 lx) for the whole space except at dawn-times. With Venetian blinds, assuming passive occupants behavior, illuminance falls within the UDI-a boundaries only in the middle of afternoon-times and below the low-

UDI-a boundary of 500 lux for the rest of time. At sunset-times, when Venetian blinds must block abundant direct sunlight, which quite absurdly yields insufficient daylighting, the DDT function of our SVM manages to ensure adequate daylighting. This key design-objective for our SVM was translated into a specification for the DDT function efficiency that we are now in a position to assess in more detail than with our simple investigation based on average point-in-time simulations. Comparing the illumination obtained with our closed SVM exposed to direct sunlight (afternoon-times) *versus* illumination produced by diffuse sunlight only, i.e. without shading system during morning-times, reveals that adequate illumination is reached in both cases. However, when considering the whole temporal map with spatial information, illumination with diffuse sunlight proves to be slightly superior than with our closed SVM made of shields with reflectance of 0.8 under direct sunlight. In principle, this reveals that the efficiency of our DDT function (η) is slightly below our specification and that the above mentioned simple investigation was too optimistic.

However, a thorough investigation (outside of the scope of this paper) revealed that our simulation provides reliable trends for spatial illuminance distributions but underestimates the amount of diffuse light scattered by the SVM, i.e. η. Such a bias is caused by an insufficient number of simulation iterations imposed by the lack of available computational power. This investigation was based on the comparison of point-in-time simulations with corresponding measurements on a mock-up of our SVM. Further investigation is needed to estimate more accurately the magnitude of this bias and reliably account for it in our results. This mock-up was also used to get insights into aesthetics of our SVM.

DISCUSSION AND CONCLUSION

We have presented the design of a shading and daylighting system customized for arid climates focused on also preserving a Middle Eastern architectural character. Such a kinetic system design, which we named "shape variable mashrabiya" (SVM), strives to maximize visual comfort and minimize solar gains, while potentially coping with the harsh local environmental conditions. Our SVM enables to switch between an open and a closed configuration depending on direct solar irradiation. The latter configuration, which consists of a three-dimensional structure, blocks most incident sunlight while transforming a fraction of it into diffuse light used for indoor daylighting (DDT function).

Our results of annual daylighting performance simulations show that, thanks to its DDT function, our SVM provides adequate (within the UDI-a boundaries) and well-balanced (most of the time across the whole space) illumination, even in the presence of direct sunlight. In particular, in contrast to typical Venetian blinds, it provides sufficient daylighting under direct sunlight at low elevation angles. Considering that our simulations provide pessimistic figures for the DDT function efficiency (see discussion in last section), our results reveal that our closed SVM with shield reflectance of the order of 0.8 should provide comparable illumination than that obtained with diffuse sunlight. In addition to increasing daylight autonomy, i.e., allowing for energy savings, we believe that our SVM design bears some architectural value and aesthetic appeal that may favor its acceptability.

Future or ongoing work covers, among other things, the design and integration of the solar responsive system, the integration of an array of SVM into a facade, investigation of energy performance and field-tests to validate the robustness of our design in arid climates.

ACKNOWLEDGMENTS

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Climate Profile for the Development of Bioclimatic Architecture in Colombia: a Comparative Analysis

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ABSTRACT

Based on the case study of two specific climatic contexts in the Andean tropic, this article sets out to demonstrate how the development of bioclimatic strategies can support architecture design in a variety of tropical climates, all this through the use of a bioclimatic profile applied to architecture.

INTRODUCTION

From nature's harmonious balance to the deterioration of the natural environment is a common path mankind has marked out through history. It's been this path on which architecture since the mid-twentieth century has left an aggregate ecological footprint with dire consequences for environmental balance and quality of life. The pursuit of human comfort in architectural design spaces at any price has been the main subject of debate among architects. The style and spectacle of architecture design has amply overridden (outstanding considerations regarding) the long-term sustainability of natural environments (López Morales, 2008).

It is from the foregoing background that the need for a more environment *responsive architecture* is drawn; the kind that can ensure quality of life going forward; one that allows for being permeated by climatic and geographic phenomena at all levels (Serra & Coch 2008); that is, one conceived from environment sustainability criteria to create conditions that promote healthful surroundings in comfortable living spaces (Givoni 1997; Serra 2009). In light of the above, it is safe to infer that moving away from an exclusively anthropocentric approach toward an ecological one represent an important challenge for modern-day architecture design.

The lack of Colombian research into the systematic design of bioclimatic strategies is the fundamental motivation for the study of a methodology of development of *bioclimatic profiles for architecture design*, which is the subject matter of this article.

AIM AND OBJECTIVE

Building a methodological reference, an ARCHITECTURE BIOCLIMATIC PROFILE, for climate analysis and a definition of bioclimatic strategies (for the Andean tropic), to be applied in two different Colombian climatic contexts.

CONCEPTUAL AND METHODOLOGICAL GUIDELINES

The work of this project takes an ecological approach to the design of passive strategies for building living spaces, which are conditioned by its surrounding variable environmental parameters and diversity of geographic phenomena. This as opposed to the design and construction of static environments in closed, airtight and rigid spaces, where sunlight and natural ventilation are replaced by mechanisms of artificial lighting and air conditioning (Serra, 2009 speaked about).

Colombia: Geographic and Environmental Context

Colombia lies in the Torrid Zone, which is characterized by high temperatures. Geographical factors and environmental parameters of the territory neutralize radiation received, making it possible for a variety of climates and ecosystems to coexist in a place, which would otherwise be remarkably hot, with a very high rate of radiation levels throughout its territory.

An abundance of geographic features, such as the Andes Range (Figure 1), mountains, lakes, swamps and rivers, sculpt the Colombian territory / topography. These make it possible for Colombia to enjoy a great variety of climates, which in turn make for the option of zoning the country strata and weather conditions, a decisive factor in achieving a better use of the solar energy resource in the construction of living spaces. This variety of conditions calls for very accurate information on the geographic and environmental determinants of each place, for the purpose of its bioclimatic characterization.

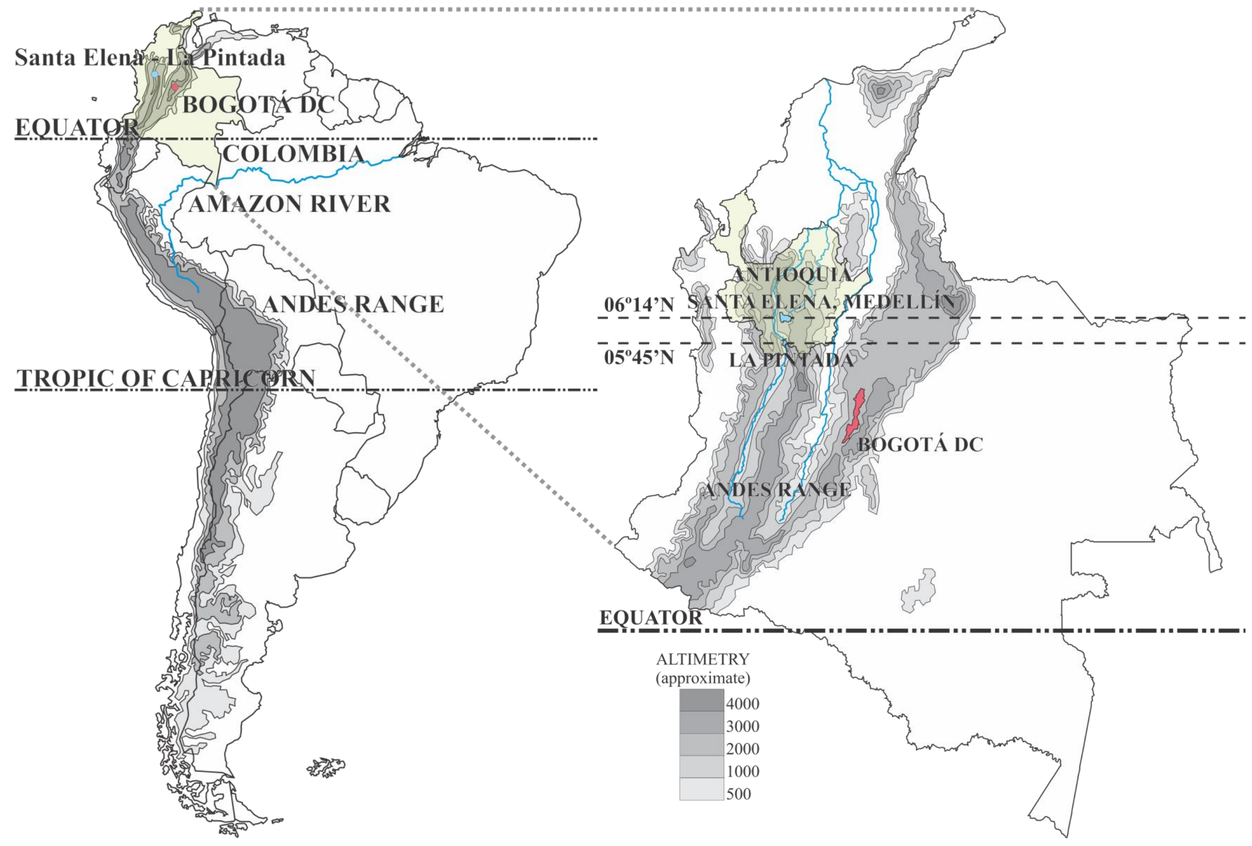

Figure 1 (a) Andes in Southamerica and (b) the Andes in Colombia.

Geographical factors related to latitude, altitude and orientation are required information, as they closely relate to the design of bioclimatic profiles in each context of the Andean region. Latitude, for instance, affects the angle of sunlight fall in both the dry and wet seasons, determining the risk of heat exhaustion and heat stroke. Altitude, on the other hand, affects the range of variability of air temperature throughout the year, which has an impact on ecological conditions (see Figure 2). The country's topographic orientation helps define the angle of incidence of sunlight, as well as the degree of exposure to the prevailing winds, which together account for the specific characteristics of ecosystems.

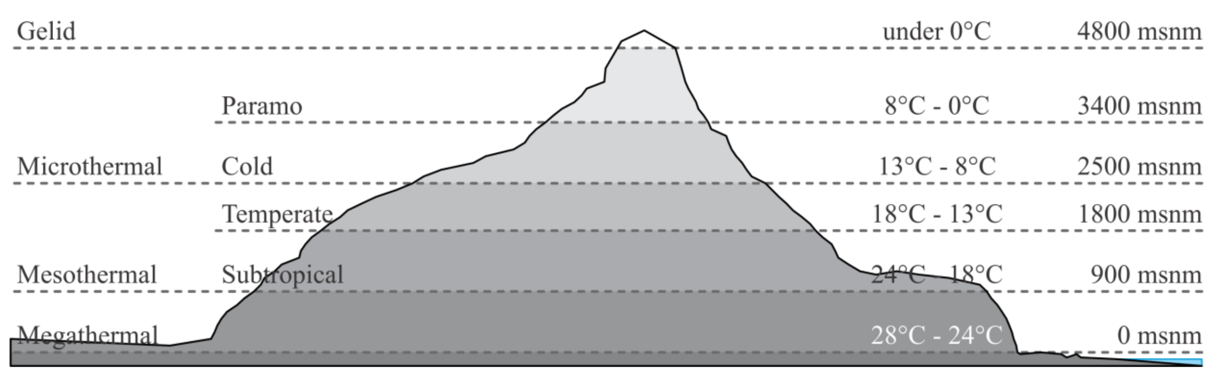

Figure 2 Schematic of geological strata by temperature.

Equally important are the environmental parameters that account for energy efficiency, which give rise to climate characterization of a territory and call for an adequate level of comfort and a decrease in pollution levels, allowing for a better experience of housing, appropriate to the climatic conditions that make up their environment.

This context presents us with the current problems faced by environmental design in architecture, especially how to resolve situations from the first developmental stages of a project, considering the efficient use of energy for a given set of geographical and environmental parameters of a project's location. The challenge is to build homes as close to the comfort zone as possible, regardless of location, whether located in climate areas as extreme as the high moors (see Figure 2), where temperature and radiation levels can be fairly low during periods of precipitation, or in the case of high temperature, low precipitation areas such as the ones found in deserts.

In terms of comfort, this work observes the rating scale proposed by McIntyre (1978) and further developed by Auliciems and Szokoloay (1997), which determines the range of temperature that can be considered comfortable for the user, known as the comfort zone, and by which it can be stated that the human body should make no metabolic effort to adapt to the environmental conditions of its surroundings, in order to feel well.

Considering the regulation of the indoor climate of buildings, has led to two different methodological approaches to addressing architectural design. One favors active strategies for climate control of buildings, with standardized criteria in design. The other favors passive strategies and considers the user as an active subject in the building, one who interacts with the environment through his relationship with architecture elements. Consequently, the definition of comfort zone is different for each bioclimatic profile, given that environmental conditions and variables are the subject of study that make up the profile.

In considering the regulation of indoor climate conditions, whether in a warm or cold tropical context, it is final orientation, which maximizes the solar resource as a source of heat and light energy, as well as, the need for ventilation. In short, the proper orientation, which is determined by the thermal bioclimatic profile, depends on which floor the project is located.

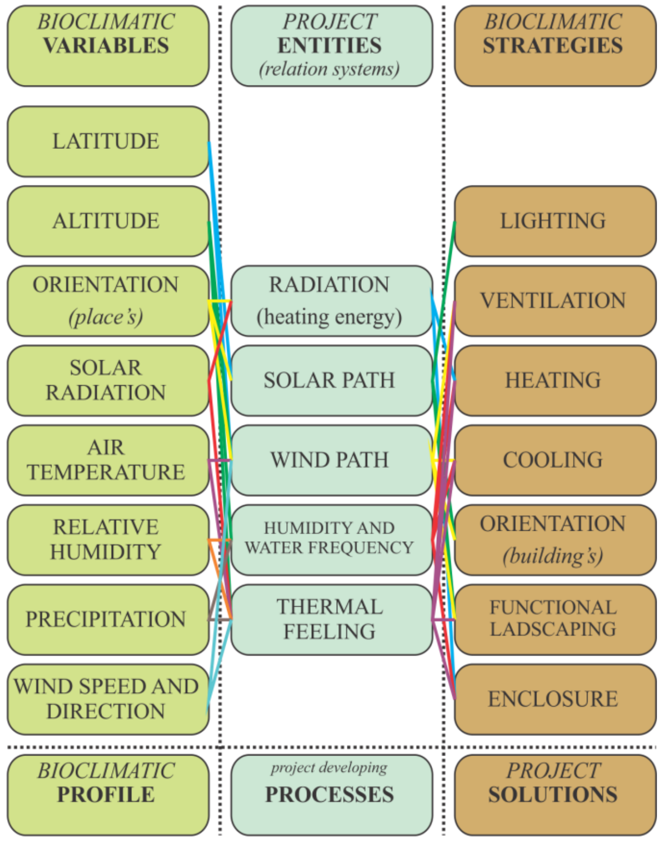

Figure 3 Methodological schematic.

Architecture Bioclimatic Profile

The purpose of an ***architecture bioclimatic profile*** is to identify the environmental variables that determine climate context, in order to analyze them in consideration of bioclimatic criteria necessary for making decisions at each stage of the architecture design process.

A project's architecture bioclimatic profile begins with the identification of those variables considered relevant, by virtue of their being constitutive of the climatic context, which affects directly the comfort of the project itself, namely, latitude, altitude, orientation, radiation level, (sunlight exposure), air temperature, relative humidity, precipitation, wind direction and speed. (see Figure 3). Climate data found through different national and international organizations are used to configure the climatic characterization of a place.

Data gathered on each of the above variables (see fig. 3, left column) become meaningful for an architecture project, once contextualized for its location, and analyzed from categories (see fig. 3, mid column) that take valuable information out of the data.

The information obtained from the characteristics of each variable reveals the energy potential available for the development of a particular architectural project. This constitutes the basis for determining the type of strategies to be implemented for energy efficiency and comfort, such as lighting, ventilation, heating, cooling, orientation, functional landscaping, and weatherization (see Figure 3).

As can be inferred from the above approach, the methodological structure of an architecture bioclimatic profile consists of a system of relationships that moves from raw data to meaningful information regarding the available energy resource, and from this, to the strategy. This proposal is a starting point to further developments concerning its subject matter.

APPLICATION OF ARCHITECTURE BIOCLIMATIC PROFILES TO DESIGN

Two towns located in northwestern Colombia serve as hosts and provide the context to implement the proposed architecture bioclimatic profile: The township of Santa Elena and the City of La Pintada, two territorial units attached to the Department of Antioquia, whose capital is Medellín.

Comparative Analysis of two Climatic Contexts

Prepared bioclimatic profile of each of the contexts to be developed (see Figure 4) A considerable climatic difference can be appreciated. It is attributable to the difference in altitude between one territory and the other (2000 m in total). Santa Elena is located atop a mountain ridge that divides two valleys, the Aburrá Valley, to the northwest, and the San Nicolás Valley, to the southwest, whereas La Pintada is nestled in the lower part of a valley which is crossed by one of the largest rivers of Colombia, and a section of whose is contoured by formidable canyons. The above characteristics are influential when analyzing the climate of an area in the Torrid Zone.

As a result of the differences identified in the bioclimatic profiles, the recommendations for bioclimatic strategies, that is the project design solutions, propose architectural designs whose adaptations vary between climates and territories. For example, lighting in St. Helena can use both direct radiation and scattered radiation, depending on air temperature and the time of day. So on the one hand, the need for solar energy is met. On the other, people can enjoy a convenient sunbath at certain times of day, when there is a chill factor. In contrast, in La Pintada, direct lighting is not recommended for a number of reasons, as it entails uncomfortable temperature increases, which are unnecessary in this place, and adversely affect the comfort of users.

As for ventilation, in Santa Elena active user intervention is recommended to ventilate the interior of living spaces, whereas in La Pintada, it is recommended that the architecture design incorporate constant ventilation systems to prevent overheating of units, and contribute to user comfort.

On the other hand, if we consider building orientation, alignment is done with taking into account the solar arc and air temperature, regarding the need for either ventilation, heating or cooling in the building, according to the characteristics of its bioclimatic profile. In short, all of the above decisions are interrelated thanks to the analysis of the architecture bioclimatic profile.

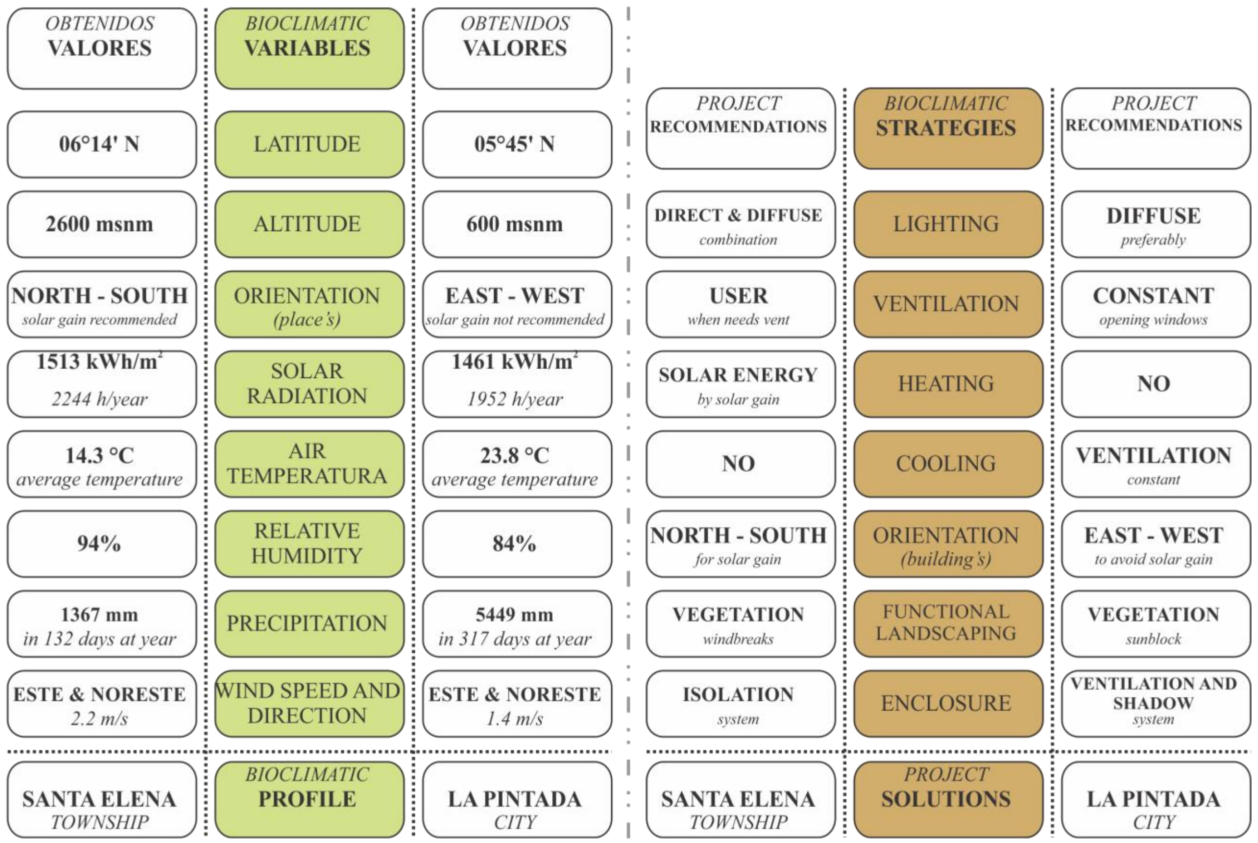

Figure 4 (a) Architecture bioclimatic profiles of Santa Elena and La Pintada; and (b) bioclimatic strategies of Santa Elena and La Pintada (climate values from IDEAM 2005; UPME & IDEAM 2005).

Based on the formula proposed by Auliciems and Szokoloay (1997), the temperature comfort zone for housing units in Santa Elena is lower than that in La Pintada (see Figure 5).

Santa Elena	La Pintada
$Tn = 17.6°C + (Tm * 0.31)$	$Tn = 17.6°C + (Tm * 0.31)$
$Tn = 17.6°C + (14.3°C * 0.31)$	$Tn = 17.6°C + (23.8°C * 0.31)$
$Tn = 22°C$	$Tn = 25°C$
Where	Where
$Zc = Tn \pm 2.5°C$	$Zc = Tn \pm 2.5°C$
Being	Being
$Tmin = 19.5°C$	$Tmin = 22.5°C$
$Tmax = 24.5°C$	$Tmax = 27.5°C$

Figure 5 (a) Calculation of comfort zone for Santa Elena and (b) calculation for comfort zone for La Pintada.

MAKING INFERENCES AND DRAWING CONCLUSIONS

Making way for an ecological approach to architecture is akin to harmonizing the comfort of living spaces with the potential of its surrounding environment, to ensure the preservation of the planet and improve the quality of life of people.

The findings of this research lead us to summarize:

The architecture design of a project should start with the climatic characterization of the environment where it will be located. This approach stands in contrast to the principles of standard architecture design, in the case of different climatic contexts.

The architecture bioclimatic profile is the basis for building a system of relations between the bioclimatic characteristics of the environment, its energy potential and the strategies proposed for achieving comfort, (besides representing a methodological reference for the customization of each architecture project within its context).

In different climatic contexts, before implementing passive strategies, it's necessary to figure how to apply the available energy sources to the generation of human comfort.

Putting together an Achitecture Bioclimatic Profile for each project means creating responsiveness to expectations of users and conditions of the environment, consolidating the two into adequate living spaces, within the criteria of durability, comfort, and efficiency in the use of natural resources, and environmental sustainability.

The field of bioclimatic architecture should a more creative, interdisciplinary endeavor that is socially responsive. Therefore, the challenge lies in transitioning from a mindset predatory of the environment to one concerting of vital living spaces in harmony with its surroundings.

NOMENCLATURE

Tn = neutral temperature
Tm = average temperature
Zc = comfort zone
Tmin = minimum temperature of the comfort zone
Tmax = maximum temperature of the comfort zone
Gelid = is the climate level located from 4800 msnm, known as gelid because of its icy temperatures and corresponds to the perpetual snow height. Presents temperatures below 0°C.
Paramo = is the climate level located between 3400 and 4800 msnm presenting temperatures from 8°C and 0°C respectively.
msnm = meters above sea level

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Energy Efficient Hospital Patient Room Design: Effect of Room Shape on Window-to-Wall Ratio in a Desert Climate

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ABSTRACT

This paper reports on a research that utilized simulation techniques for identifying the most efficient hospital patient room designs and their associated window-to-wall ratios. Simulation of the energy consumption and daylighting performance of common patient room designs were conducted using a range of Window-to-Wall Ratios (WWRs). The paper focuses on arriving at solutions that balance between the reduction of energy consumption and the achievement of proper daylight distribution in the desert climate of Cairo, Egypt. Simulations were conducted using the Diva-for-Rhino, a plug-in for Rhinoceros modelling software to interface with the Energy Plus, Radiance and Daysim software. Results demonstrated that solar penetration is a critical concern affecting patient room design and window configuration in desert locations. Use of the outboard bathroom patient room design was found to be the least efficient among the tested alternatives. Although it has a smaller external wall size, it failed to provide energy consumption that is lower than that of the other options. Its best energy performance was 20% higher than that of the nested bathroom patient room design. However, the outboard bathroom design allowed for larger WWRs (70%-90%), which might prove useful for external view exposure purposes. The nested and inboard bathroom patient room designs provided better energy performance. However, this was on the expense of window size. The acceptable cases of these designs had smaller WWRs, (30%-40%). The results of this paper demonstrated the need for the careful consideration of the size of windows and openings in relation to different patient room designs. Simulation techniques can prove useful in this regard.

INTRODUCTION

Hospitals are typically considered one the most energy demanding building types. Patient rooms compose the largest volume of hospital buildings. The external walls of patient rooms represent the most significant part of the external surface area of these buildings. Windows can contribute significantly to the healing process and reduction of pain and length of stay in hospitals through the provision of daylight and allowance of external view (FGI, 2010). However, they can also contribute negatively to the energy consumption of these buildings, especially in desert climates, where the cooling load represents a significant percentage of total energy consumption.

Sizing the windows of patient rooms should be carefully considered in relation to patient room shape. Some common patient room designs have a small external wall surface area with a large room depth, while others have larger external room surfaces and a reduced depth of the work area. The windows of patient rooms should minimize solar penetration, reduce overheating; yet at the same time maximize daylighting and patient access to external view. The objective is to reduce the total energy load while maintaining comfort and quality health care.

Literature addressed the effect of environmental aspects on healthcare delivery. Ulrich recommended that natural light improvement could help reduce stress and fatigue, while increasing effectiveness in delivering care, patient safety and overall healthcare quality (Ulrich, 1991 and Ulrich et al., 2004). In an attempt to develop patient room designs to create healing environments, the effect of natural daylight on the patients' average length of stay in hospitals was investigated. Studied factors were patient's average length of stay as an index of health outcome, and the differences in environment during daylight hours, such as illuminance, luminance ratio, and illuminance variation in the hospitals patient rooms (Choi et al., 2012).

In research work more relate to this study, energy efficient building envelope treatments were examined for a generic reference hospital in Thailand. Parametric analysis was conducted. The overall thermal transfer value, glazing material, Window-to-Wall ratio (WWR) and external shading devices were addressed. The annual energy savings due to increasing daylighting reached up to 15.4% and 11.3% for the electrochromic and green tinted glazing respectively (Chungloo et al., 2001).

Optimization of window opening in a hospital patient room was addressed in a research that aimed at providing daylighting, external view, while minimizing the energy consumption. An optimization methodology was demonstrated through parametric computer simulations to determine the optimum window design in the form of window width, sill and lintel heights and shading device depth (Shikder et al., 2010). The impact of using various window shading systems and different window glazing types on the energy consumption of a typical hospital Intensive Care Unit room space in Egypt was examined. It was found that energy savings reaching up to 30% could be achieved by the use of externally perforated solar screens and overhangs positioned at a shading angle of 45° (Sherif et al., 2013-a).

In another study, daylighting performance was simulated for a typical hospital Intensive Care Unit room space located in Cairo, Egypt. Several window configurations were simulated in the four main orientations, where the effect of adding shading and daylighting systems was examined. Successful window configurations were recommended for different window to wall ratios (Sherif et al., 2013-b).

The above review of literature demonstrates that a limited number of publications addressed with the relationship between hospital patient room designs and the associated window configurations. Research work concerned with this relationship in desert environments is almost nonexistent. Configuring the windows of patient rooms for energy efficiency, while providing acceptable daylighting levels, could pave the way for reaching more sustainable hospital designs.

OBJECTIVE

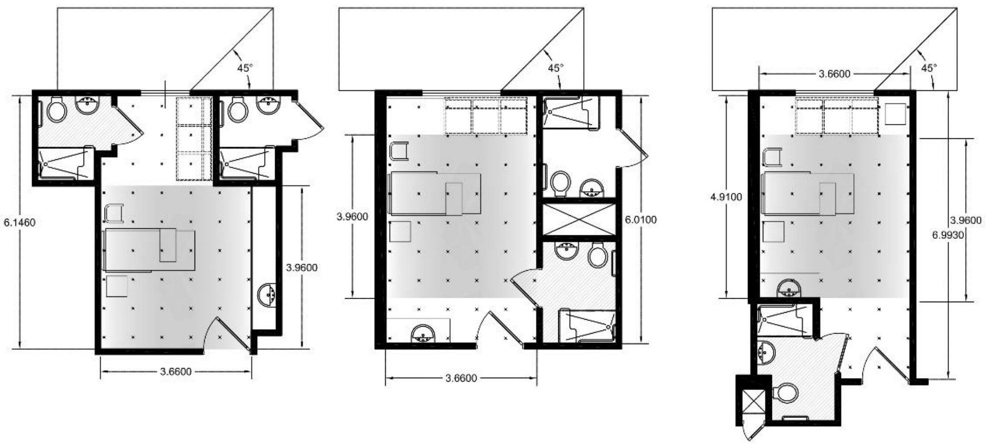
This paper aimed to compare the energy consumption and daylighting performance of common hospital patient room designs. Investigation focused on the design of windows facing the south orientation under the desert clear-sky of Cairo, Egypt. The larger aim was to arrive at satisfactory patient room designs that minimize energy consumption and maximize the utilization of daylighting, thus help improve the delivery of sustainable healthcare facilities.

METHODOLOGY

The methodology was divided into two consecutive stages. Stage one investigated the energy performance of the tested patient room design cases along with the alternative window configurations. Stage two concentrated on the analysis of daylighting adequacy for the cases which achieved acceptable performance in stage one. Three of the most common patient room designs were selected for investigation. These were: Design A: the outboard bathroom patient room design; Design B: the nested bathroom patient room design; and Design C: the inboard bathroom patient room design. The tested rooms were assumed to have a similar floor area (22 m²). The layout, dimensions and parameters of the tested rooms are shown in Table 1 and Figure 1.

Table 1. Parameters of the Tested Patient Room.

Internal Surfaces Materials		
Walls	*Reflectance*	*50% (Medium Colored Internal-walls Off-White)*
Ceiling	*Reflectance*	*80.0% (White Colored Ceiling)*
Floor	*Reflectance*	*20.0% (generic floor)*
Window Parameters		
Glazing		*Double glazing clear (VT=80 %)*
Sun Breaker	*Reflectance*	*35.0% (Outside Facade)*



Design A:
The Outboard Bathroom

Design B:
The Nested Bathroom

***Design** C:*
The Inboard Bathroom

Figure 1 The tested patient room designs

Seventeen window size values, expressed as Window-to-Wall Ratios (WWRs) were analyzed for each patient room design. The values ranged from 10% to 90%, at 5% increments. The shape and location of the tested windows alongside the external wall of the patient room space are illustrated in Figure 2. A horizontal sun breaker was assumed to be positioned on top to the window. Its overhang value provided a sun protection angle of 45°, as shown in Figure 3. This angle was based on the results of previous research work (Sherif et al., 2013 b).

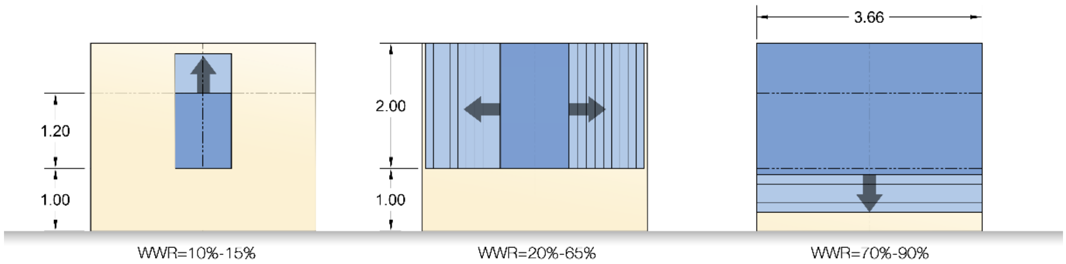


Figure 2 The shape and position of the tested window on the external wall at different WWRs.

Simulations were conducted using the climatic data of the city of Cairo, Egypt (30°6'N, 31°24'E, alt.75 m) that enjoys a year-round desert clear-sky. The city is characterized by a hot-arid desert climate, according to Köppen-Geiger (2006). The tested patient rooms were assumed to be located on the second floor level of a hospital building, where windows were assumed to face no external obstruction. The external ground surface was assumed to have a 20% reflectance value. Grasshopper which is a plugin for Rhinoceros modeling software and a parametric modeling tool was used to automate the energy and daylighting simulation process. By activating this function, the Grasshopper plugin generated a parametric model for each WWR and ran a climate based analysis through DIVA interface. Energy simulation was conducted using the EnergyPlus software. Daylight simulation was conducted using the Radiance and DAYSIM software. The Diva-for-Rhino plugin for the Rhinoceros modeling software was used as an interface.

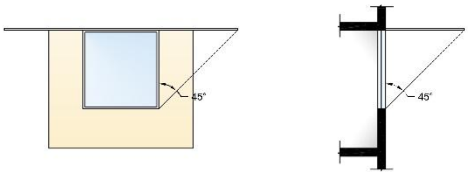


Figure 3 The overhang of the shading device protecting the tested window.

Methodology of Stage One: Energy Consumption Analysis

The aim of this phase was to investigate the energy consumptions associated with the three tested patient room designs (cases A, B and C). The annual energy consumption resulting from the different WWRs of each patient room design was calculated. The cooling, heating and lighting energy consumption values were accounted for. The WWRs which resulted low energy consumption values falling within 3% from the lowest value for a certain patient room design were considered acceptable cases for such as design.

Energy simulation parameters were selected to focus on studying the performance associated with room shape and window configuration. The effect of thermal transmittance through walls and ceiling from the adjacent spaces was neutralized. Thus, the thermal transmittance from all walls and ceiling, except that of the window wall, were set to be adiabatic. The effect of the adjacent rooms was considered to be of no relevance to the thermal performance sought in this comparative study. The building was assumed to be fully air conditioned and minimal thermal transmittance was expected from the other internal spaces that would have identical set conditions. The external wall was defined as a 0.35 m thick double brick insulated cavity wall with a U- value of 0.475 W/m² –k that carried the tested window at its center. The air conditioning system heating and cooling set points were assumed to be 22°C/26°C respectively. The occupancy time of the studied patient room was chosen to be all day, at a rate of 10 m²/ occupant. The hourly lighting schedules that were generated through the annual Daylight Availability analysis by the Radiance and DAYSIM software were used as basis for artificial lighting energy calculations. This artificial lighting was set to be dynamically controlled by sensors according to daylighting adequacy.

Methodology of Stage Two: Daylight Availability Analysis

The aim of this stage was to evaluate the year-round daylighting performance of the cases that proved successful for each of the three design configurations in stage one. Simulation parameters used in investigations were: ambient bounces = 6; ambient divisions = 1000. The occupied time of the patient room was assumed to be from 06:30 AM to 10:30 PM. In this study, the reference plane on which daylighting performance was simulated was the patient bed level plane (0.90 m height). The spacing of the analysis grid was set at 0.7m * 0.7m. Four points were placed on the patient bed. The reference plane contained 46, 54 and 53 measuring points in each of the three tested patient room designs A, B and C respectively, as shown in Figure 1. The illuminance value was assumed to be 300 Lx (IESNA, 2000).

Three Daylight Availability evaluation levels were used (Reinhart & Wienold, 2011). First, the "daylit" areas were those areas that received sufficient daylight at least half of the year-round occupied time. Second, the "partially daylit" areas were those areas that did not receive sufficient daylight at least half of the year-round occupied time. Third, the "over lit" areas were those areas that received an oversupply of daylight, where 10 times the target illuminance was reached for at least 5% of the year-round occupied time. Two daylighting acceptance criteria had to be satisfied. First, 100% of the patient bed surface area should be "daylit". Second, at least 50% of the patient room area should be "daylit".

SIMULATION RESULTS

Results of Stage One: Energy Performance

The total annual energy consumption values expressed in Kwh/m² were calculated. The results are as shown in Table 2. It summarizes the energy consumption results in the south orientation at different WWRs for the three investigated room designs A, B and C. The cases that achieved the required threshold were highlighted with a light tone in the table.

Table 2. Total Annual Energy Consumption for Layout Designs A, B and C

Annual Energy Consumption (Kwh/m2)																	
WWR%	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Design A	180	192	189	186	184	182	177	178	177	177	176	176	173	175	174	175	176
Design B	169	168	153	151	147	147	147	150	154	158	162	167	171	174	177	180	183
Design C	173	175	166	158	154	151	155	158	160	161	163	169	174	177	178	180	183

Use of design B that has a nested bathroom resulted in the lowest energy consumption among all three room design types. The consumption was as low as 147Kwh/m2 in WWRs 30%-40%. Moreover, design C (inboard bathroom design) achieved a very close value of 151 Kwh/m2 in WWR 35%. Use of these designs resulted in a better performance in comparison with Design A (outboard bathroom design) which failed to produce a value lower than 177 Kwh/m2. Furthermore, use of Design A resulted in the highest energy consumption among all alternatives. It reached 192 Kwh/m2 at 15% WWR. On the other hand, its consumption was lower than the other two alternatives at high WWR values. Using a 90% WWR with designs A and B resulted in comparatively larger energy consumption values, reaching up to 183Kwh/m2.

On the other hand, the outboard bathroom design configuration (Design A) achieved larger window sizes and larger number of options in comparison with the other two layout configurations. The acceptable WWR range of Design A extended from 40 to 90%. Fewer acceptable WWR choices and smaller window sizes were identified for the nested bathroom configuration (Design B). These ranged from 20% to 45% WWR. A very limited range of WWRs was found acceptable in the inboard bathroom configuration (Design C), where only three WWR cases (30 to 40% WWR) met the required criterion. In design A, the bathroom location on the outboard wall reduced the size of the exposed external wall surface, thus reducing the thermal exposure of the patient's room to the hot desert climate. However, this was overcome by the increased artificial lighting energy load, as explained later. This was not the case in the nested and inboard designs, where the size of the external wall surface was much larger.

To explain the behavior described above, the lighting, cooling and heating consumption values were analyzed. As expected for a desert environment, cooling represented the highest values, followed by lighting electricity then heating loads, which were almost negligible as shown in Figures 4, 5 and 6.

The performance of design A is shown in Figure 4. The lighting electricity load significantly decreased with the increase of WWR. This could be attributed to the increase of daylighting use, which resulted in a reduction of artificial lighting. However, the nature of the patient room plan type resulted in overall higher levels of artificial lighting, with subsequent high cooling energy. On the other hand, the cooling energy loads slightly increased with the increase of WWR. This allowed the acceptance of larger WWRs, reaching up to 90%. The use of an outboard toilet with the resultant small external wall surface dampened the effect of changing the WWR. This was observed in the gentle curve slope of the cooling energy consumption for WWRs 20%-90% that it is almost flat.

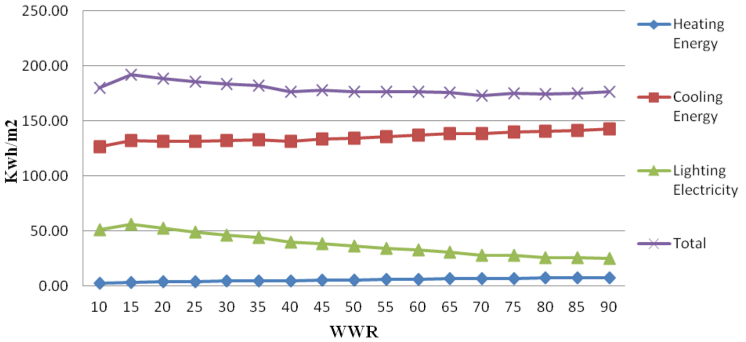


Figure 4 Design A annual cooling, heating, lighting and total energy loads for different WWRs.

The performance of Design B is shown in Figure 5.The lighting electricity load decreased at a constant rate with the increase of WWR, while the cooling energy loads increased considerably with the increase of window to wall ratio (WWR). This is observed in the considerable increase and the curve slope of the cooling and the total energy use from 40% to 90% WWR. This could be attributed to the design of this patient room type that has a nested toilet that is associated with a larger external wall surface. This increased solar exposure and allowed the window transmitted solar energy.

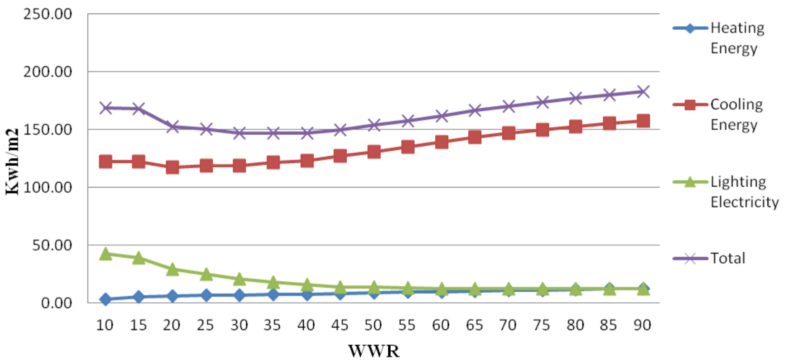


Figure 5 Design B annual cooling, heating, lighting and total energy loads for different WWRs.

The energy consumption of patient room Design C is shown in Figure 6. This design was found to produce behavior almost similar to that of Design B. Both share a large exposed external wall. It was noticed, thought that the cooling energy of design C was slightly higher than that of Design B. This could be attributed to the cooling load resulting from the slightly increased lighting electricity.

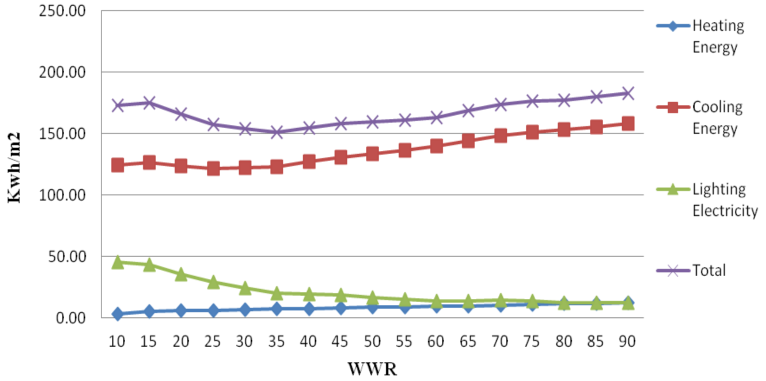


Figure 6 Design C annual cooling, heating, lighting and total energy loads for different WWRs.

Results of Stage Two: Daylight Availability Analysis

In this stage, the cases that achieved successful energy performance in stage one were evaluated for daylighting adequacy. Results are shown in Table 3. In Design A, acceptable daylight availability was only achieved at large WWRs. Only 5 of the tested cases passed the daylight availability test in this case. On the other hand in Design B, 4 of the 5 tested cases resulted in acceptable daylighting performance. In Design C, all of the three tested cases resulted in an acceptable daylighting performance.

Table 3. Percentage of "Daylit" Area Relative to Patient's Room and Bed Plane Areas

WWR %		25	30	35	40	45	50	55	60	65	70	75	80	85	90
Design A	Room				26	28	35	39	43	48	54	61	63	72	70
	Bed				0	25	100	100	100	100	100	100	100	100	100
Design B	Room	41	54	57	65	80									
	Bed	100	100	100	100	100									
Design C	Room		60	58	62										
	Bed		100	100	100										

For more detailed discussion, eleven cases were analyzed for the outboard bathroom design (Design A). Simulation results revealed that the amount of acceptable "daylit" areas was directly proportional to the increase of WWRs values. Only large windows achieved adequacy in the case of the outboard bathroom design. For WWRs between 70% and 90%, the "daylit" area reached 72% of the space area, especially at 85% WWR. The "partially daylit" areas dominated the patient room, where it reached 50% of the space in average (40% to 65%). However, it decreased gradually until it became unnoticeable at 85% WWR (15% of the space). In contrast, the "overlit" area was almost constant (13% as an average) in the tested WWRs.

On the other hand, when the bathroom was located in-between two adjacent patient rooms (Design B: The nested bathroom), only four cases from five energy efficient ones achieved adequacy (30% to 45% WWRs). The "Daylit" area reached 80% of the space, at a WWR value of 45%. Although, the "daylit" area of the patient bed plane achieved adequacy in the 25% WWR case, it was unacceptable in relation to the overall patient room area testing (41% "daylit" area). The "Partially daylit" area decreased gradually until it almost disappeared (1%), in the case of 40% WWR.

For the inboard bathroom design (Design C), the three energy efficient cases (30%, 35% and 40%WWRs) were acceptable for daylighting performance. The "daylit" area values for the patient room space were almost similar (60% at an average). For the three design configurations, the "over lit" area percentages did not exceed 15% in average for overall the patient room space in all accepted daylight availability cases.

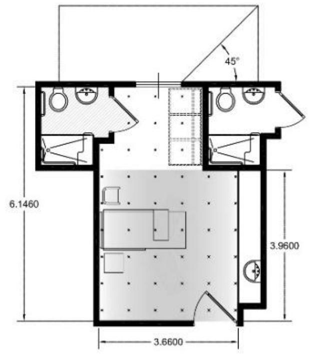
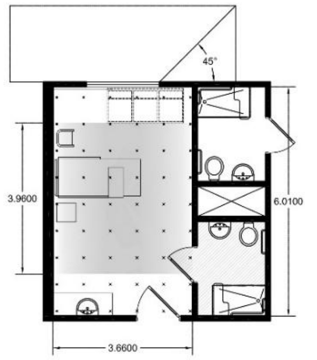
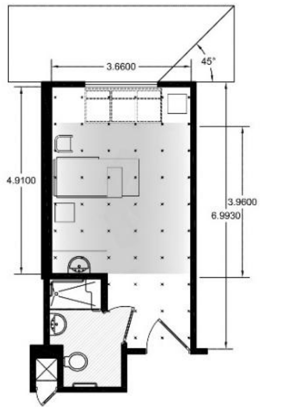
CONCLUSION

The energy and daylighting performance of three common patient room designs were simulated. The performance resulting from use of a range of window sizes (expressed as Window-to-Wall Ratios - WWRs) under the clear-sky desert sun of Cairo, Egypt was examined for each of these room designs. Table 4 summarizes the range of WWRs that were recommended for each patient room design for satisfying the energy and daylighting criteria. In addition, the balanced WWRs that satisfy both energy and daylighting criteria at the same time were identified.

Results of this study demonstrated that solar penetration is a critical concern affecting patient room design and window configuration in desert locations, like in Cairo, Egypt. Use of the outboard patient room design was found to be the least efficient among alternatives. Although it has a smaller external wall size in comparison with the other alternatives, it failed to provide an energy consumption that was lower than that of other two tested room designs. Its best energy performance was 20% higher than that of the nested bathroom design. This could be attributed to the increase of artificial lighting that resulted from allocating the bathroom along the external façade in the outboard bathroom design. However, the outboard design allowed for larger WWR values. This might prove useful for external view exposure purposes. Although the nested bathroom and inboard bathroom designs provided better energy performance, this was on the expense of window size. The acceptable cases of these designs had smaller WWRs, between 30% and 40%.

The results of this paper demonstrated the need for a careful consideration of the size of windows and openings in relation to different patient room designs. Simulation Techniques proved useful in identifying the wiNdow configurations that satisfy both the energy and daylighting requirements at the same time.

Table 4: Recommended WWRs for Patient Room Designs A, B and C

<table>
<tr><th rowspan="2">Patient Room Designs</th><th>Design A</th><th>Design B</th><th>Design C</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Energy</td><td>40% - 90%</td><td>30% - 45%</td><td>30% - 40%</td></tr>
<tr><td>Daylighting</td><td>70% - 90%</td><td>30% - 90%</td><td>30% - 90%</td></tr>
<tr><td>Balance</td><td>70% - 90%</td><td>30% - 45%</td><td>30% - 40%</td></tr>
</table>

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Study on the Microclimatic Conditions and Thermal Comfort in an Institutional Campus in Hot Humid Climate

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ABSTRACT

The built form alters the microclimate significantly which in turn affects the outdoor thermal comfort. The outdoor thermal comfort depends on the ability of the materials to absorb solar radiation (albedo) and the geometrical arrangement of the buildings and its morphology. The aim of this study is to investigate the influence of the built geometry and its morphology on the outdoor thermal environment in an institutional campus in the hot humid city of Chennai. The study is twofold. Firstly, the impact of built geometry on the microclimatic conditions was assessed through field measurements and secondly a questionnaire survey on thermal sensation in the campus environs of Sathyabama University was conducted to study the subjective response of students to the outdoor thermal environment in a hot humid climate. The field measurements included the monitoring of meteorological parameters such as air temperature Ta, relative humidity RH, wind speed v and mean radiant temperature Tmrt. Outdoor thermal comfort conditions were assessed through the physiologically equivalent temperature (PET) index, during daytime at different built morphology. The influence of various built parameters such as Sky view factor (SVF), building materials, green cover, etc., on microclimatic conditions and the daytime thermal sensation were assessed. This study also attempts to identify various passive design options in order to arrive at favourable microclimatic conditions and to improve pedestrian comfort conditions during daytime in an institutional campus.

INTRODUCTION

The built form alters the microclimate significantly which in turn affects the outdoor thermal comfort. Built form is characterized by replacement of the natural earth's surface by hard impervious layer; buildings and its geometry; and the properties of the dense construction materials. Also, the outdoor thermal comfort depends on the ability of the materials to absorb solar radiation (albedo), the geometrical arrangement of the buildings and its morphology. The dense construction materials stores the heat and increases the surface temperature, the building geometry (defined by the ratio of height of the buildings to the width of the street) traps the incident solar radiation, the hard impervious pavements, roads and parking lots increases the surface runoff of water and the reduced vegetation increases the air temperatures at the microclimate level thus influencing the thermal comfort of the pedestrians. Enhancement of the outdoor thermal comfort is possible through careful analysis of the built form and its influence on the microclimatic parameters. Therefore, this paper aims at investigating the influence of the built geometry and its morphology on the outdoor thermal environment in an institutional campus in the hot humid city of Chennai.

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BACKGROUND LITERATURE

At the micro level, building geometry shows an intimate relationship with air temperature, and Oke (1976) states that the thermal climate at the canopy layer depends on the characteristics of the individual site and not on the temperature at boundary layer. The height-to-width ratio and the street orientation with respect to solar radiation, was found to have a great influence on the timing and magnitude of the energy regime of the individual urban surfaces (Nunez and Oke 1977). Oke (1981) states that the rate of cooling at the street level depends on two parameters: the Height – width ratio (H/W, street geometry) – the ratio of typical height of the buildings to typical width of the neighbouring streets and the sky view factor - the fraction of the sky hemisphere visible from a location at the street level in an infinitely long urban street canyon. Arnfield (1990) compared the effects of urban geometry and thermal properties of the construction materials and found that the canyon geometry is the predominant factor and the thermal properties of the materials enhance the differences in the cooling rates generated by different street geometries. The canyon radiative geometry contributes to a decrease in the long-wave radiation loss from within the street canyon due to the complex exchange between buildings and the screening of the skyline and decreases the effective albedo of the system, because of the multiple reflection of short-wave radiation between the canyon surfaces (Oke et al 1991). Ahmed (1994) found a decrease in air temperatures by 4.5K with an increase in the H/W ratio from 0.3 to 2.8, in the hot humid city of Dhaka, Bangladesh, in summer. Also, the aspect ratio and the street orientation determines the time of exposure to direct solar radiation and the occurrence of extreme heat stress (Ali-Toudert and Mayer 2006). Shashua-Bar (2006) indicated that the thermal effects of built form, vegetation and colonnades, in streets and in courtyards depend on the envelope ratio (i.e.,), the overall geometry factor. Johansson and Emmanuel (2006) analyzed the influence of street canyon geometry on the outdoor thermal comfort in Colombo, Sri Lanka and the study revealed that the differences in air temperatures were higher during the day, especially in the afternoons when compared to the night and a maximum difference of 7^{o}C was found between sites.

It is difficult to predict the actual thermal sensation of humans because of the varying climatic conditions in the outdoors and the changes in the personal factors such as the clothing and activity level. PET – a universal outdoor thermal comfort index (Jendritzky et al 1990, Matzarakis et al 1999), is defined as the "Physiologically Equivalent Temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed" (Mayer and Hoppe 1987).

The field of research pertaining to outdoor thermal comfort conditions especially at the street level is relatively new. Matzarakis and Mayer (1998) investigated the thermal component of different urban microclimates in Freiburg, Germany and found that the heat stress levels of the human beings depend mainly on the shading effects and clothing factors. Ali-Toudert et al (2005) found that the heat stress in unobstructed locations is high, when compared to sheltered urban sites in Beni-Isguen, Algeria. Ali-Toudert and Mayer (2006) found the dependence of thermal comfort on the design of the street, including geometry, orientation and other design strategies, such as the galleries and horizontal overhangs. Gulyas et al (2006) examined the outdoor thermal comfort conditions in the complex urban environment of Szeged, Hungary using the RayMan model and found a difference of 15^{o}C to 20^{o}C in the PET index due to the radiation differences in sites that were shaded differently by buildings. Emmanuel and Fernando (2007) insisted that the mitigation strategies adopted by urban designers should be based on human comfort (determined by both MRT and air temperature), rather than on simply attempting to control air temperature alone. Lin et al (2010) indicated that low SVF and sufficient shading with tress and buildings can improve the thermal comfort during summers. Bourbia and Boucheriba (2010) highlighted the importance of street design in Constantine-Algeria and found a difference of 3–6^{o}C in air temperatures between the streets with varying geometry. Also, the wind speed reveals a significant impact in the relationship between the MRT and the SVF, even though solar access has a strong relationship with SVF than the wind speed (Kruger et al 2011). The study on the seasonal effects of urban street shading by Hwang et al (2011) revealed that shading effects provided different thermal sensation at different seasons and suggested that improvement of comfort conditions in urban streets should be based on the requirements of seasonal shading levels. Amirtham et al (2011) found that the differential heating which occurred due to the different aspect ratios of the street canyons resulted in different climatic conditions in urban built forms.

Studies relating to the impact of urban geometry on human comfort conditions in India are very few and deals mostly with indoor comfort conditions. Chowdhury and Ganesan (1983) identified that physiological strain over most parts of India is due to the heat and accounts for nearly 80% of the stress. Jauregui (1991) characterized different human climate conditions in the tropical cities using the Effective Temperature index (an index of heat stress on the human body) and found that the comfort levels are significantly reduced while walking on the streets due to the high radiation levels. Thus, this study attempts to contribute to the understanding of the relationship between built form, air temperatures and comfort conditions in an institutional campus in the hot humid city of Chennai, India.

AREA OF STUDY

Sathyabama University is an institutional campus in the suburbs of Chennai experiencing hot humid climate. The maximum air temperatures during summer (May and June) varies between 38°C and 42°C and the minimum air temperatures during winter (December and January) varies between 18°C and 20°C. The average monthly relative humidity ranges from 63% (June) to 80% (November) and the vapour pressure varies between 22.6hpa and 32hpa.

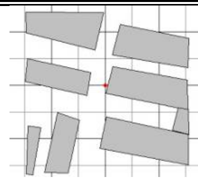
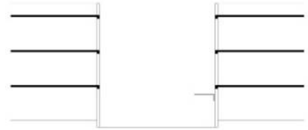
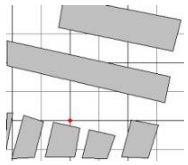
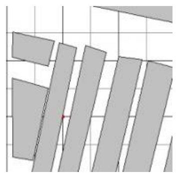
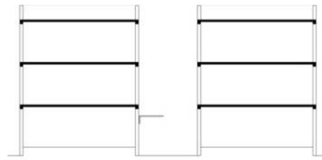
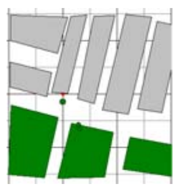
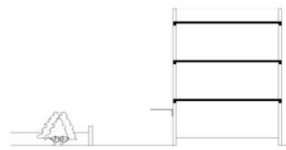
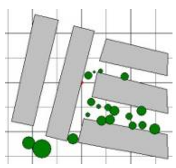
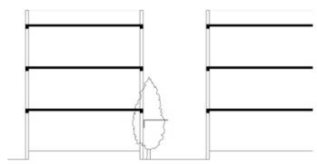
The institution houses several academic blocks of varying street geometry enclosing open spaces and streets for interaction. Five different locations in the campus were selected considering various parameters such as the percentage of vegetation, orientation of streets and canyon geometry (H/W ratio). The street geometries identified for the study ranged from 0.5 to 2 (H/W ratio). The thermal properties of the built surfaces were similar in all locations. Figure 1 shows the measurement locations in the campus and Table 1 shows the characteristics of the selected locations.

Figure 1 Measurement locations in the Campus

METHODOLOGY

The impact of built geometry on microclimatic conditions was assessed through field measurements. The air temperature and relative humidity data were measured continuously on an hourly basis using HOBO dataloggers (HOBO U20 Temp/RH) in the selected locations. The wind speed and the cloud cover data from the Nungambakkam Meteorological station were used for the study as the above data could not be measured at study area. Microclimatic variations of the selected locations were analyzed for a hot day in May (summer). The influence of urban morphology on outdoor thermal comfort conditions is calculated through the most commonly used outdoor thermal comfort index - Physiologically Equivalent Temperature (PET) (Matzarakis et al 1999, Emmanuel 2005, Johansson 2006). RayMan Pro model (Matzarakis et al 2007, 2010) has been used to calculate Physiologically Equivalent Temperatures as it takes into consideration all environmental factors influencing thermal comfort. The model calculates the radiation fluxes within the complex urban environments based on the time of the day and year, meteorological parameters (air temperature, humidity, degree of cloud cover), surface morphological conditions (geographical locations, building geometry, albedo of the surrounding surfaces, sly view factor) and personal data (age, height, weight, clothing, activity level.

Table 1. Characteristics of the Measurement Locations

Site	Plan	Section	SVF	H/W
Location 1			0.467	1
Location 2			0.623	0.5
Location 3			0.240	2
Location 4			0.362	0.5
Location 5			0.271	1.67

The 200m X 200m grid along with their shadow patterns and Sky View Factor (SVF) are shown in Figure 2. Also, a questionnaire survey on thermal sensation in the selelcted locations was conducted to study the subjective response of students on outdoor thermal environment. The subjective response of respondents and PET Index were compared to identify the appropriate built geometry for thermally comfortable environment.

RESULTS AND DISCUSSIONS

The influence of urban morphology on outdoor thermal comfort conditions were analyzed with respect to parameters such as orientation, street geometry (H/W ratio) and percentage of vegetation. The air temperature and PET variations at five selected locations are shown in Figure 3. Mayer et al (2009) states that the atmospheric conditions are modified by the urban processes and built form; and results in increase or decrease in ambient air temperatures which is a function of various parameters such as weather, time and day of the year, street geometry and built structure. Amongst the five locations in the campus, location 1, 3 & 5 are oriented in the N-S orientation and location 2 & 4 are oriented in the E-W direction.

Air Temperature and PET Analysis

The air temperature and PET were analyzed with reference to orientation, street geometry and percentage of vegetation of selected locations.

Orientation, The selected streets in the campus were oriented in the N-S and E-W directions. The air temperatures in the E-W oriented street at location 2 were higher than N-S oriented streets (location 1,3,5) through out the day (8.00hrs to 16.00hrs). Even though location 4 had similar orientation and

Figure 2 Calculated Shadow Patterns and SVF at various locations using RayMan Pro 2.1

street geometry as that of location 2, temperatures were almost similar to that of N-S oriented streets except at 14.00hrs which could be attributed to the shading of the instrument. The variation in the air temperatures with resepect to orientation (E-W vs N-S) were higher at during daytime when the sun's radiation is at the maximum ranging from 1.47^{o}C at 10.00hrs to3.7^{o}C at 14.00hrs. The outdoor comfort conditions with respect to PET values also varied from 2.1^{o}C at 10.00hrs to 6.6^{o}C at 14.00hrs. The study also found that PET values were lesser than air temperatures at 6.00hrs and 18.00hrs thus reinforcing the fact that absence of direct solar radiation increases the comfort conditions i.e., thermal sensation. The PET values were as less as 3.39^{o}C when compared to air temperatures at 6.00hrs.

Vegetation, Except locations 4 & 5, the absence of vegetation in other locations nullifies the cooling effect through shading and evapotranspiration. Even though the street geometry and orientation

(E-W) of locations 2 & 4 were same (H/W = 0.5), their thermal recordings varied upto 3.28^{o}C at 14.00hrs, due to presence of vegetation at location 4. The N-S oriented streets at location 1 & 5, also experienced significant thermal differences of about 2.3^{o}C at 14.00hrs, attributed mainly due to the presence of significant vegetation at location 5.

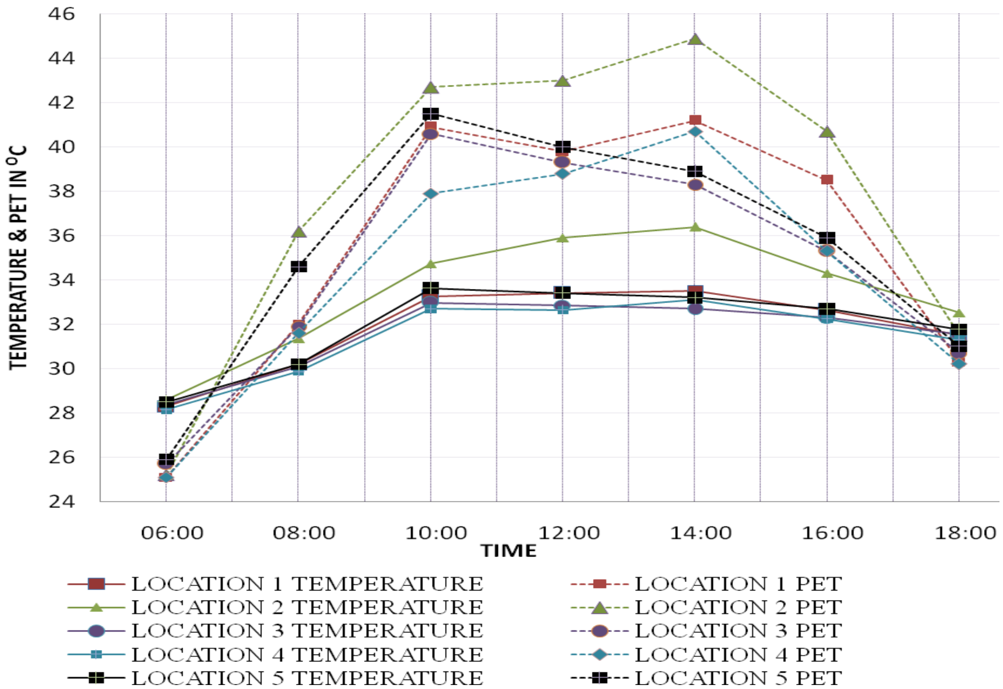


Figure 3 Air temperature and PET variations at various locations

Street geometry, The variations in air temperatures with respect to height to width ratio increases gradually from 8.00hrs (1.1^{o}C) to 14.00hrs (3.7^{o}C) and reduces from 18.00hrs reaching almost similar temperatures at 6.00hrs. The H/W ratio is inversely proportionate to air temperatures and PET values, i.e., higher the H/W ratio lesser the air temperatures and PET values. Thus the study reveals that narrow streets are comfortable during daytime due to internal shading of buildings in hot humid climates, thus improving the outdoor comfort conditions.

The comfort conditions expressed by PET values were higher than the air temperatures by 8.5^{o}C during daytime (8.00hrs to 16.00hrs) attributed to the presence of intense solar radiation. In the absence of direct solar radiation, the human thermal sensations represented by PET values were lesser than the air temperatures upto a maximum of 3.39^{o}C lesser than the air temperatures. Analysis also revealed higher variation in PET values when compared to temperature differences at location 2 & 3 at 14.00hrs. For a temperature difference of 3.7^{o}C between location 2 & location 3 at 14.00hrs, PET differences of 6.6^{o}C existed at the same locations. This indicates that even slight variation in air temperatures can have a significant impact in the comfort conditions (PET) during daytime.

Location 2 experienced the maximum temperature and PET values at 14.00 hrs owing to its E-W orientation of the street, H/W ratio of 0.5, SVF of 0.623 and absence of vegetation. Also the concrete pavements and absence of shading by trees and buildings added to the discomfort. Almost all the five locations were above the upper limit of discomfort of 33^{o}C as stated by Ahmed (1994), during daytime (between 07.00 hrs and 17.00hrs). The temperature in the PET index increases with the increase in ambient air temperatures and the difference between the same is as high as 8.5^{o}C at 14.00hrs. At 6.00hrs the PET was lesser than the air temperature by 3.05^{o}C at location 4 which recorded the minimum temperature. This clearly reveals that the outdoor thermal comfort index has a significant impact with direct solar radiation. PET index during night time was comfortable and was well within the upper limit of comfort (33^{o}C) and was also lesser than the ambient air temperatures.

Questionnaire Survey and PET Analysis

The questionnaire survey revealed that the respondents experienced the heat stress during daytime as the PET varied from 34.6^{o}C to 44.9^{o}C between 8.00hrs and 16.00hrs. The thermal sensation at locations 3 & 5 was almost tolerable at 14.00hrs due to internal shading by buildings and trees. The N-S orientation of these locations had a significant impact on the thermal sensation. Location 1 which was also oriented in N-S direction experienced higher discomfort due to its street geometry with SVF of 1. The thermal perception of the respondents was too warm at locations 1 & 2 due to the absence of internal shading. Also the reflective nature of the abutting buildings had a significant impact on the thermal sensation in the above locations. In general the thermal perception at locations 1, 2 & 4 were not satisfied and the users experienced heat stress. The overall conditions inside the campus are acceptable for the users near the locations 3 & 5 due to the N-S orientation and the presence of vegetation, thus providing a tolerable environment at these locations.

CONCLUSION

The air temperature and the PET trends in the campus revealed that the nights were comfortable when compared to day. During daytime, all the streets were uncomfortably hot with the PET values well above the upper limit of the comfort zone. As the daytime comfort was found to have a significant correlation with the street geometry (SVF), presence of vegetation and orientation, the study indicates the significance of improving the daytime comfort in the campus, by stipulating appropriate built geometry and orientation in the new developments in campus. Also if the concept of internal shading is adopted in the existing built form, it can improve the comfort conditions to a significant level. Based on the study, recommendations pertaining to some of the aspects of built form have been suggested to improve the outdoor thermal comfort conditions at the campus.

- N-S oriented streets are comfortable when compared to E-W orientation. If E-W orientation is essential in the design, then appropriate shading of streets through shaded corridors, projected balconies, and vegetation can improve the pedestrian comfort considerably in campus.
- Shading through vegetation significantly reduced air temperatures and PET values during daytime irrespective of the orientation.
- Narrow streets oriented in the N-S direction reduced the heat stress during daytime as they reduce the time of exposure to direct intense solar radiation. Also the internal shading of buildings accelerated the comfort conditions at pedestrian level.

NOMENCLATURE

PET	=	Physiologically Equivalent Temperature (^{o}C)
H	=	Height of building (m)
W	=	Distance between buildings in a street canyon (m)
SVF	=	Sky View Factor
OUT_SET*	=	Outdoor Standard Effective Temperature (^{o}C)
SET*	=	Standard Effective Temperature (^{o}C)

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Session 7B : Performance evaluation and design feedback

PLEA2014: Day 3, Thursday, December 18
10:25 - 12:05, Compassion - Knowledge Consortium of Gujarat

The Ability of Current Rating Tools to Guarantee Sustainable Successes: Balance and Perspective

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ABSTRACT

The use of assessment and rating tools by design teams is increasing. In a parallel development, demonstration projects aimed at improving sustainability in building are being increasingly endorsed. This paper addresses the question of whether projects that have been assessed and rated are necessarily worthy of designation as 'sustainable successes', leading to enhance the reproducibility of up-front sustainability measures, ultimately broadening the base for sustainable building.

Within the field of contemporary European sustainable group housing, actual projects that have been assessed and rated are explored and positioned relative to recognised demonstration and best practice projects. Focus lies primarily on projects supported and rated by the BREEAM (Building Research Establishment Environmental Assessment Method). In order to increase the reliability, outcomes are verified by cases rated with other multi criteria sustainability tools. The study is conducted from the perspective of the architect-designer, focusing on actual sustainable design measures and features as comparative parameters with reference to the two most tangible pillars of sustainable building (i.e. 'Planet' and 'People').

The results of this illustrative study indicate that the assessment and rating tools that are currently available cannot guarantee full success with regard to sustainability. Projects that have been assessed and rated do not necessarily constitute 'best-practice projects'. The analysis raises several issues regarding sustainability tools and suggests perspectives with regard to 'design attitude'. Promising perspectives involve appropriate and integrated design measures, a conceptual approach and, most importantly, architectural solutions.

INTRODUCTION

Once they realise the necessity of an integral approach to sustainability, architect-designers are faced with a complex task. Multi-disciplinary actors in the construction industry are undertaking frantic efforts to facilitate this task by focusing on the development of assessment and rating tools. The use of these tools is increasing, not only as a means of evaluating buildings with regard to their sustainability, but also as a design supporting tool (Abdalla, Maas, Huyghe and Oostra, 2011). Parallel to the development of such incentives, multiple authors and public organisations are endorsing the importance of demonstration projects in the quest for more sustainable building (Buijs & Silvester, 1996) (Feminas, 2004) (Van Hal, 2000).

Two issues are relevant in this regard. First, the outcome of an assessment is highly dependent upon the set of components and indicators incorporated into the selected tool. For this reason, some projects might not cover the full scope of sustainability. Second, 'demonstration and best-practice projects' are receiving considerable attention in both the popular media and the scientific literature. Nevertheless, their performance with regard to sustainability has rarely been tested according to the most prominent and widely used multi-criteria assessment methods. Combined with the increasing general interest in sustainability tools, this could mortgage the recognition of the sustainability value and benefits that such projects offer.

This study focuses on actual projects that have been assessed and rated according to the BREEAM (Building Research Establishment Environmental Assessment Method). The main objective of this chapter is to explore and position these projects relative to renowned European demonstration and best-practice projects. This positioning can provide a preliminary answer to the question of whether projects that have been assessed and that have achieved high ratings are necessarily worthy of designation as best-practice projects that intended to enhance the reproducibility of up-front sustainability measures, ultimately broadening the base for sustainable building. The analysis raises several issues and suggests perspectives with regard to 'design attitude'.

METHODOLOGY

The research and argumentation of this study can be characterised as a cross-case comparison in tabular form. Case-study methodology is appropriate for investigating contemporary phenomena (e.g. sustainable building) (Yin, 1994). In order to increase reliability, multiple projects are considered. The study is conducted from the perspective of the architect-designer, focusing on actual sustainable design measures and features as comparative parameters with reference to the two most tangible pillars of sustainable building (i.e. 'Planet' and 'People').

The literature contains no consensus regarding the content and naming of sustainable design measures and features. A self-compiled set was therefore made for this study. The determination of these comparative parameters, the analysis of the comparison and the formulation of issues and perspectives is based on empirical observations, as well as on a review of literature regarding selected demonstration and best-practice projects. These resources are supplemented by a tentative theoretical description of sustainable building in the European context. This abductive reasoning can be seen as an iterative process between the collection and analysis of empirical material and the study of theory in literature (Feminas, 2004).

Assessment and rating tools are intended to evaluate performance related to various aspects of sustainability. This study examines projects that have been assessed and rated according to the most prominent and most widely known and used system in Europe: BREEAM ("BREEAM Meest Toegepaste Certificering"). In this system, credits are awarded in nine categories and added together to produce a single overall score, positioned along a scale ranging from 'Pass', 'Good' and 'Very Good' to 'Excellent' and 'Outstanding'.

As suggested in the literature, demonstration projects should meet the following conditions: repeated evaluations, an open and public character and the intention to act as a demonstration project from the beginning, as well as a special character (Buijs & Silvester, 1996) (Van Hal, 2000) (Keating & Peach, 1989).

The projects addressed in this study were selected from within the field of grouped housing in Europe. Specific features of these projects (e.g. overlapping scales, collectivity) contain embedded aspects of sustainability, as well as opportunities for realising additional sustainability measures, although they are also accompanied by critical barriers.

From the projects that have been assessed and rated by the BREEAM, the following were selected for this study: 'De Balk van Beel' in Belgium and 'Sanderstead Road' in the United Kingdom. Both are compared according to the self-compiled set of comparative parameters. Another project featuring typological similarities to 'De Balk van Beel' was added to the research in order to enhance the specificity of the comparison and to illustrate the stated perspectives: 'Kronsberg' in Hannover (Germany).

This study, derived from an ongoing doctorate dissertation (Janssens, ongoing) is illustrative and primarily representative of the selected case studies and of the assessment and rating tool. The methodology of using comparative parameters, based on Feminas (2004), is considered relevant, although it is not the only approach possible. The set of comparative parameters is neither exhaustive nor definitive. Finally, the perspectives suggested within the specific theoretical framework should be seen as one of many possible solutions.

IDENTIFICATION OF SELECTED ASSESSED AND RATED PROJECTS

The 'De Balk van Beel' involves the pilot construction within an ongoing new neighbourhood development ('Tweewaters') in Leuven. The project comprises four upper floors containing 101 different housing units. The ground floor contains shops and services for the neighbourhood.
Upon completion of the design, the project was assessed using the 'International Bespoke 2010' version of the BREEAM, which resulted in an 'interim design stage' certification. The design achieved a score of 87.81%, which corresponds to an 'outstanding' rating. The development achieved 100% of the available credits in the categories of 'Management', 'Health & Wellbeing' and 'Land Use & Ecology', and it scored over 90% in the categories of 'Energy' and 'Transport'.

The new housing development 'Sanderstead Road' is located on a derelict brownfield in the London Borough of Croydon. It comprises a three-storey block of 38 one-bedroom and two-bedroom flats, partly constructed over three new ground-floor commercial units, with two blocks of three-storey semi-detached, four-bedroom houses in the courtyard area. Assessment using the 'EcoHomes 2006' version of the BREEAM resulted in an 'interim design stage' certification. The overall score of 75.41% corresponds to an 'excellent' rating. The project team performed well across all categories, particularly in relation to 'Materials' and 'Management'.

Figure 1 Selected cases for the cross-comparison: left 'De Balk van Beel'; right 'Sanderstead Road'. Source: Bart Janssens

CROSS-CASE COMPARISON

Table 1 provides a tabular comparison of sustainable design features and measures of the selected BREEAM projects with exemplary practices in Europe. Data are subdivided into two categories: 'embedded sustainability features' and 'added sustainability measures'. The first category covers features that are at least partially inherent in the field of grouped housing. The second category includes measures added through some level of deliberate effort, either at the neighbourhood level or at the building level.

A description of the complete list of comparative parameters and a thorough discussion of the comparison is not possible within the limited length of the paper. As this comparison represents the basis of the argument of this research, it will be discussed and documented in depth during the oral presentation.

Table 1. Cross-case comparison of sustainability design features and measures.

	Exemplary practices		BREEAM projects	
	Prevailing demonstration projects	'Kronsberg'	'De Balk van Beel'	'Sanderstead Road'
Embedded sustainability features				
High density (≥ 50 units per net hectare)	●	●	●	●
Collective meeting spaces	●	●		
Extensive range of housing types	●	●	●	●
Recreation areas	●	●		
Semi-private courtyards with residential quality	●	●		
Transitional zones private-collective-public	●	●		○
Bright naturally lit collective internal circulation	●	●		
Well monitored collective spaces	●	●		
Well monitored public spaces	●	●	●	
Added sustainability measures				
Neighbourhood level				
Combined heat and power plant	●	●	○	
Open storm-water system: ponds, open canals	●	●		
Storm-water infiltration units			○	○
Constructed wetland (e.g. helophyte filter)	●	●		
Sewage wells	●		●	●
Cycle & pedestrian friendly routes by design	●	●	●	
Cycle & pedestrian friendly routes by infrastructure				●
Electric recharging plug-in points for cars	●		●	
Storage facility and recycling station	●	●	○	●
Green-blue networks	●	●	●	○
Kitchen gardens	●		○	
Building level				
Bioclimatic design (e.g. compactness, orientation)	●	●		
Micro-climatic spaces: glazed balconies, greenhouses	●	●		
Solar accessible large windows	●	●		
Green roofs/façades	●	●	●	
Sun-protection louvers, greenery	●	●		
Sun-protection fabric			●	
Storage facility and recycling station	●		○	
Internal spatial flexibility	●		●	
Sound insulation (improved imposed standards)	●		●	●
Ecologically responsible materials (≥ 80%, BREEAM, or Cradle to Cradle when available)			●	●
Rain-water recycling system	●	●		●
Energy-efficient and water-efficient appliances	●	●	●	●
Low energy performance level (40-60kWh/m²)	●	●	●	●
High-efficiency natural gas condensing boiler	●		●	●
Natural ventilation (e.g. wind cowls)	●	●		
Mechanical ventilation	●	●	●	●
Solar panels	●			●
Sub-metering for energy use	●	●	●	●
Real-time energy monitoring		●	●	●
Home delivery boxes			●	
Electronic butler service			○	
One-key access			●	
Implemented measures	●			
Postponed or expired measures	○			

ANALYSIS OF THE RESULTS FROM THE CROSS-COMPARISON

As revealed in the cross-case comparison, the selected BREEAM projects lack most of the sustainability features that they are assumed to include. Little or no attention is paid to the intermediate scale or to the collective or semi-public space. With regard to the list of additional measures, the projects incorporate few, if any bioclimatic design principles, while other measures exceed most of the project examples contained in the cross typology (e.g. real-time energy-monitoring systems and home-delivery boxes). Many similarities can be observed with regard to low energy performance and provision of energy-efficient and water-efficient appliances.

The measures prevailing in the demonstration projects and the BREEAM projects differ in terms of their overall character. While most demonstration projects assign priority to tangible, architectural solutions, the BREEAM projects tend to focus more on relatively technological measures (e.g. open storm-water systems versus storm-water infiltration units; wind cowls versus mechanical systems).

The selected BREEAM projects show only limited aspects of social sustainability. The lack of embedded sustainability features and the nature of the sustainability measures applied result in the absence of 'people features'. The assessment of projects with a tool containing components and indicators that emphasise a more social approach to sustainability (or even a better-balanced set of components) would change performance in terms of sustainability.

As demonstrated in comparative studies, most tools have their own content, areas of focus and methods (Fowler & Rauch, 2006) (Saunders, 2008). The outcome of an assessment depends heavily upon the set of components and indicators which are included in the selected tool. Yet included aspects of sustainability are listed and rationally tackled in the hope of achieving intended desired rating. In many cases, design teams resort to technological and even highly innovative measures. This can have two consequences. First, such strategies increase investment costs. Second (and often related to the first consequence), there is a true risk that measures will be postponed or will even expire during the further design and/or construction process. The analysis of the 'De Balk van Beel' reveals that certain key measures have been cancelled (e.g. electronic butler service) or transferred to future neighbourhood developments (e.g. combined heat and power plant, recycling station, kitchen gardens) (Janssens, 2013). Other measures are mentioned only as options (e.g. storm-water infiltration unit) or seem to be to innovative (e.g. home delivery boxes). The BREEAM score obtained during the design phase hence does not necessarily guarantee the building's final sustainability performance. Particular measures can prove to have different outcomes during the construction and usage phase. This finding corresponds to results reported by Ding (2007) and by Abdalla et al (2011).

By promoting designs oriented towards solving single problems, assessment and rating tools apparently steer architects/designers towards less than optimal measures. Creativity comes at the expense of easy 'add-on' technological solutions, thus eliminating opportunities and inspiration for liveable, creative and efficient living and working environments. This single-problem approach to sustainability is likely to result in sustainability decay, as illustrated by the BREEAM projects addressed in this case study.

PERSPECTIVE AND ILLUSTRATIVE VERIFICATION

Gaining efficiency and decisiveness will require a shift in focus from checklists and performance criteria to practical sustainability measures, which are more appropriate for architect-designers. The 'design attitude' of architects/designers with regard to sustainability should shift from measures intended to resolve single problems towards multiple integrated measures, concepts and architectural solutions. The practice of finding 'promising combinations' is the common ground for both sustainable transition and sustainable design (Tjallingii, 1996). Thinking in terms of design combines possible solutions from disciplines that are fundamentally different (Cross, 2006) (Van Bakel, 1995).

Measures are deliberate and distinct decisions intended to fulfil specific requirements and to achieve desired features. Measures that serve several requirements can increase efficiency, diminish (or even eliminate) objections to implementation and reduce the risk of postponement and/or expiration. As described by Janssens and Van Dorst (2012), 'Beneficial Pattern Measures' (BPM) are building-design measures that have positive effects on multiple targets. Applied to sustainability, BPMs aim to satisfy both environmental ('Planet') and social ('People') pillars/components/indicators (Figure 2). Common BPMs in European demonstration projects include 'glazed balconies' and 'greenhouses', often as components of the lighting, heating, cooling and/or ventilation design. With regard to the 'People' aspects of sustainability, these measures enhance social contact between owners and passersby, in addition to their ability to enhance social control, create potential spaces for identification and expansion, and provide a transitional zone between public and private spaces. These primarily 'Planet'-oriented measures also address a wide range of 'People' aspects.

Despite the use of BPMs, individual sustainability measures cannot address the full range of sustainability issues, and they often generate sub-optimal solutions. Multiple measures must be combined in a mutually reinforcing manner, resolving any disadvantages or bottlenecks. 'Beneficial Multiple Pattern Measures' (BMPM) combine several promising BPMs into successful sustainability packages. In many cases, the BPMs that are outlined (e.g. 'glazed balconies' and 'greenhouses') are replaced by simplified versions (e.g. 'large windows'). In the demonstration project 'BO-01' in Malmö (Sweden), an 'open storm-water system' was placed in front of the buildings, broadened and supplemented with 'plants' near 'large windows' (Figure 3). In addition to being an interesting and attractive feature in an urban context, this solution is able to regulate privacy. The creation of a distance and the presence of plants avoid the need to cover the windows, thus preventing them from losing their previously stated potential for serving important functions.

Given the context-specific nature of every assignment, BMPMs must be composed and combined into an integrated approach with regard to all predefined requirements, terms and conditions. A conceptual approach is crucial when working with 'integrated multiple measures'. The development of concepts prevents inefficiencies in later design stages, and it increases the likelihood of sustainable success in a cost optimal way (Rovers, 2008). Concepts facilitate the successful implementation of measures by focusing on the achievement of several objectives in an integrated manner (Figure 2). This can be defined as a 'Beneficial Pattern Concept' (BPC).

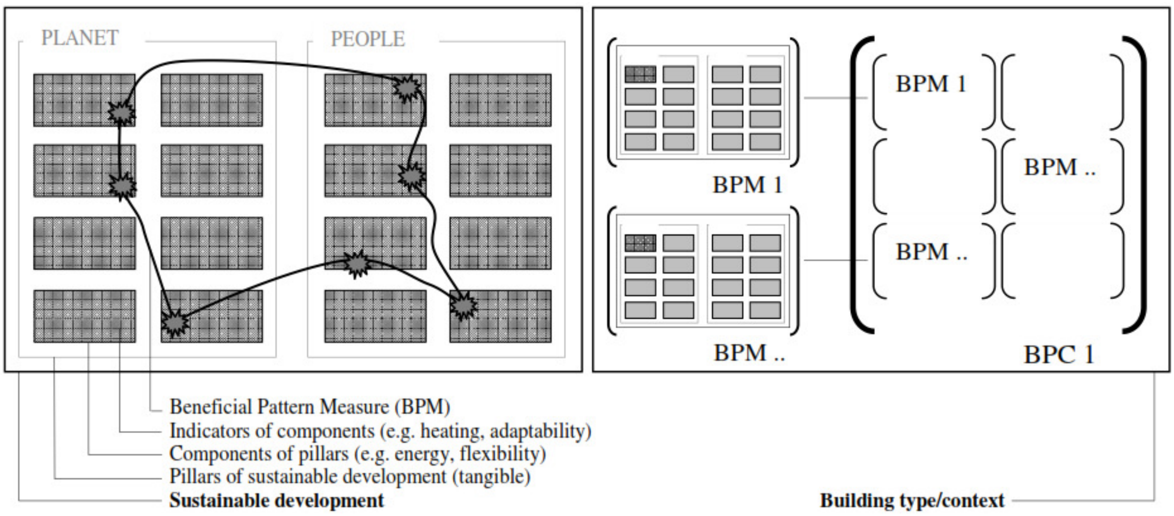

Figure 2 Figurative representation of 'Beneficial Pattern Measures' (BPM) and 'Beneficial Pattern Concepts' (BPC). Source: Bart Janssens (2013)

The ‘Kronsberg’ project contains architectural solutions within a strong conceptual approach. Dwelling units were placed back-to-back, facing east and west, and separated by a covered atrium (Figure 3). During a test case for research by design, the atrium was optimised with regard to sustainability. It was also implemented and developed into a full BPC (‘the bioclimatic street’) for a typology resembling that of ‘De Balk van Beel’. Verification of architecture and sustainability revealed that the concept is effective and efficient, coupling aspects of sustainability (e.g. water, ecology, energy, health, comfort, social value and architectural design) with regard to both environmental and social sustainability.

Figure 3 Left: example of a ‘Beneficial Multiple Pattern Measure’ (BMPM) in ‘BO-01’ in Malmö: ‘open storm water system’ – ‘plants’ – ‘large windows’. Right: example of a ‘Beneficial Pattern Concept’ (BPC) in ‘Kronsberg’ in Hannover: ‘the bioclimatic street’. Source: Bart Janssens

The development of new measures and the optimisation of existing measures and concepts could be stimulated against the background of a theoretical and practical framework based on knowledge concerning particular sustainability measures (e.g. scope, promising combinations, deferability, adaptability, added ability). Architect-designers can indulge their creativity, thereby broadening the base for sustainability, ultimately generating a sustainable transition for the built environment.

FINALIZING REMARKS

Outlook verification: In order to increase the reliability, outcomes will be verified by other cases, which will be discussed and documented in depth during the oral presentation. Research will be based on empirical performance data derived from occupied buildings. Within the BREEAM assessed and rated projects, ‘Futura’ (Zoetermeer, The Netherlands) will be investigated. Within other multi criteria sustainability tools, following projects will be reviewed: ‘Cortinghborg’ (Groningen, The Netherlands) rated by ‘GPR Gebouw’; ‘Eco-Life’ (Kortrijk, Belgium) rated by ‘Vlaamse Maatstaf voor Duurzaam Wonen en Bouwen’; ‘Les Dominos’ (Lyon, France) rated by ‘HQE’.

Future research and discussion: There are a number of future research and discussion topics concluded to be relevant. First, in order to prevent the introduced BPMs, BMPMs and BPCs in becoming as impenetrable and convulted as the ticked boxes of most multi criteria assessment and rating tools, a clear and ‘architect-designer friendly’ knowledge structure is needed. Second, when setting out such knowledge structures it is most important to rely on factual evidences in order to avoid preconceptions. Because of the often occurring discrepanties between the results of assessments and actual performances of designs/buildings, research should study actual ‘real-life’ buildings more closely. Sustainability tools should learn and improve from past projects. Third, the focus in next steps in the development of assessment and rating tools is plural: the improvement of methods of evaluation and shortlisting of relevant and appropriate criteria for each project, the recognition and accountance for synergies between performance criteria, a more holistic audit (full sustainability scope) and monitoring approach, etc. In tackling these issues focus should be on architectural and contextual measures and issues in order to encourage integrated 'People-Planet solutions'. A system thinking approach between assessment tools and knowledge structures, i.e. matching evaluation criteria and e.g. BPMs, is believed to be promising.

Preliminary conclusion: This illustrative study on selected BREEAM projects demonstrates that current assessment and rating tools cannot guarantee complete success in the area of sustainability. Projects that have been assessed and rated do not necessarily constitute 'best-practice projects'. Most current tools have a unilateral focus on checklists and/or performance criteria for a selection of sustainability aspects, thereby encouraging the practice of designing to solve single problems. In many cases, this can lead to a single orientation with regard to sustainability, possibly leading to sustainability decay. Tools can facilitate success in sustainability, on the condition that their constituting components and indicators cover the full scope of sustainability, and provided that architect-designers are aware that sustainability arises from engagement with the complexity of the situation, and not from checklists. A theoretical and practical illustrative framework with regard to an 'integrated multiple design attitude' indicates that, regardless the use of sustainability tools during or after the design process, the keys to success in sustainability include knowledge about and the implementation of appropriate and integrated design measures, a conceptual approach and, most importantly, architectural solutions. Research is needed on a suitable knowledge structure and the linkage with optimized assessment and rating tools.

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Numerical study: How does a high-rise building affect the surrounding thermal environment by its shading?

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ABSTRACT

In rural Japanese cities, many old and densely populated urban districts have been replaced by high-rise residential buildings because of urban redevelopment. High-rise building affects the sunshine conditions and wind environment of the surrounding areas. These problems have been already discussed; however, it is rarely discussed how high-rise buildings affect the outdoor and indoor thermal environment of their surroundings. Particularly, shading is a serious problem in winter because it makes the outdoor environment colder and increases the energy consumption for heating of adjacent buildings in addition to daylight shortages.

The shading effect of a high-rise building on the outdoor and indoor thermal environment in winter is simulated by a 3D CAD-based thermal environment simulator. As a result of the simulation, shading effect by high-rise building at noon extends widely to the area apporoximately 200m away in the north, but the 7 °C difference in the mean radiant temperature in the shaded area is caused by the surrounding space geometry and material. Also, in the northern or western street of high-rise building, many shops exist and their façade with large windows make the shading effect on the building heat load more remarkable. The building heat loads of these buildings are more than 30% larger than that in the case when the high-rise part is removed.

INTRODUCTION

In rural Japanese cities, many people used to live in densely populated urban districts near train stations with many prospering businesses nearby. However, because of decreasing district population and development of suburban areas, many district buildings were vacated and replaced by high-rise residential buildings, and many businesses closed.

High-rise buildings cause problems such as preventing access to sunlight, and creating strong wind conditions, and affect the landscape. When constructing high-rise buildings in Japan, the building height is regulated by the Building Standards Law. The law has a regulation about indexes such as duration of solar shading and sky factor from the viewpoint of access to sunlight. Moreover, in several cities, environmental assessments are required when the height of high-rise buildings is greater than 100 m. For these assessments, wind conditions are simulated using CFD (RANS).

As previous studies, Saito (2003) researches the effect of high-rise building on the illuminance and sky factor on the surroundings. Also, Curreli (2011) researches solar access in densely built urban environments. However, it is rarely discussed how high-rise buildings affect the outdoor and indoor thermal environment of their surroundings. As mentioned above, shading is a serious problem in winter. In particular, shading by high-rise building makes the neighboring outdoor environment colder, and increases the energy consumption for heating.

This study reveals the shading effect of a high-rise building on the outdoor and indoor thermal environment in winter using numerical simulations. The building heat load is calculated considering the effect of the outdoor thermal environment. An urban district with and without high-rise buildings are reproduced using the 3D CAD system and then compared.

METHODOLOGY

Target urban district

The target district is in Tsuchiura city, which is approximately 60 km from Tokyo in the north, and is located in the city center near Tsuchiura Station. The district has high pedestrian traffic and several shops. Low-rise shops and residential buildings were closely built, and commercial and high-rise residential buildings were first built in 1997. Furthermore, parking lots have replaced many of the original houses and shops. The height of the high-rise building in the target district is 109 m, with a north-facing open space for events. The high-rise building affects the thermal environment of the surrounding outdoor spaces, particularly the thermal radiation environment of sidewalks and parking lots. Moreover, it affects the thermal environment of the surrounding buildings, and the shading owing to the high-rise building increases the energy consumption for heating.

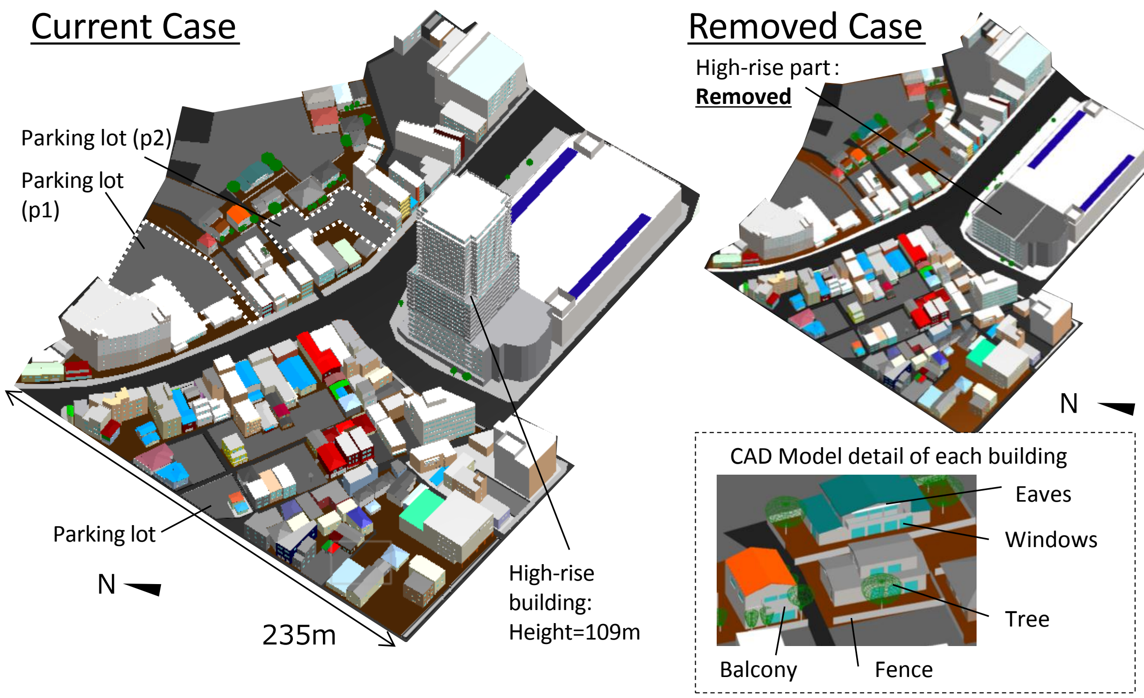

Figure 1 3D CAD model of the target urban district

Simulation method

In order to reveal the effect of shading owing to the high-rise building on the thermal environment of outdoor and indoor spaces, we analyzed the thermal environment in the target urban district using an in-house 3D CAD-based thermal environment simulator (Jiang H. et al., 2009; Asawa T. et al., 2008).

We collected spatial geometry and material data for 2009 and constructed 3D CAD models of the site at a scale of 1:500 (Sato R., et al., 2009). Two models were constructed; the first (current case) reproduces the current state, whereas the second (removed case) reproduces the state when the high-rise part is removed from the high-rise building.

Next, we calculated the outdoor surface temperature distribution in the target district under clear sky conditions in winter using the 3D CAD-based thermal environment simulator (Weather condition: Fig. 2). First, the 3D spatial forms of buildings, trees, and other structures and the 2D ground surfaces are divided into voxel mesh grids (mesh size: 400 mm). Then, the outdoor surface temperature for each grid was determined by solving the unsteady-state 1D heat balance equation in the vertical direction of the surface. The terms of the heat balance equation are direct solar radiation, sky solar radiation, reflected solar radiation, atmospheric radiation, longwave radiation exchange with surroundings, convective heat transfer, latent heat transfer, and conductive heat transfer. Each radiation is calculated by the ray tracing method, and the convective heat transfer is calculated assuming outdoor uniform distribution for the outdoor air temperature and wind velocity.

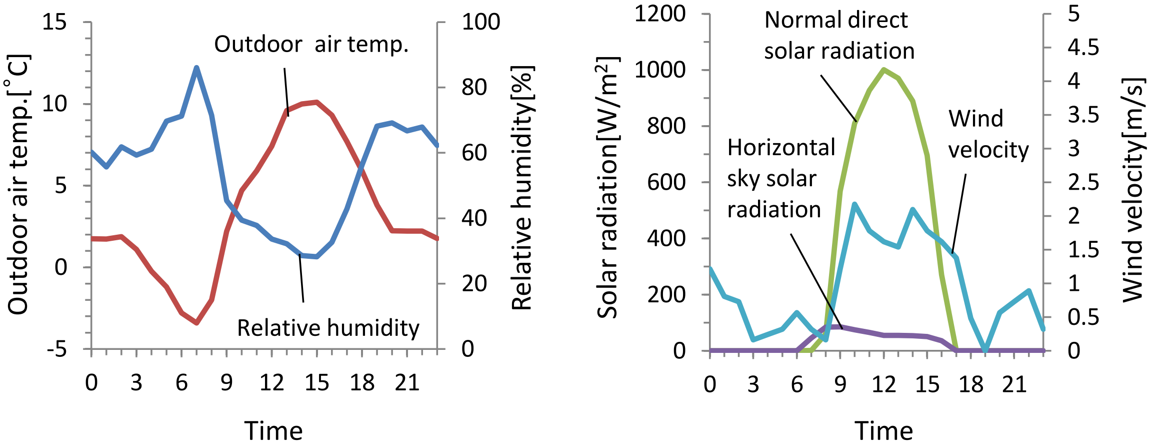

Figure 2 Weather conditions (December 21, a clear sky winter day)

The thermal radiant field in the urban district is evaluated using mean radiant temperature (MRT) at a height of 1.5 m. The MRT is calculated using the following equation, as the shortwave and longwave radiation absorbed by humans. Rhuman is the solar radiation and longwave radiation absorbed on the human surface, calculated from equation (2).

$$MRT[°C] = \sqrt[4]{R_{human}/\sigma} - 273.15 \quad (1)$$

$$R_{human} = a_1 \left\{ \frac{A_p}{S_{human}} \cdot I_d + \sum_{i=1}^{6} W_i (I_{si} + I_{ri}) \right\} + a_2 \sum_{i=1}^{6} W_i \left(L_{object_i} + L_{sky_i} \right) \quad (2)$$

Furthermore, the building heating loads, which consider the effect of surrounding buildings and trees, are calculated using the calculated total radiation and surface temperature distribution on the building's external surfaces. To evaluate the effect of the outdoor thermal environment on the building's indoor thermal environment, each building floor is assumed to be a single room. We further assume that the air-conditioning system is set at 20 °C all day in winter, and the internal heat gains' schedule is based on the standard model of the Architectural Institute of Japan (Architectural Institute of Japan, 1985).

RESULTS AND DISCUSSIONS

Effect on the thermal radiation environment of the outdoor space

Surface temperature distribution

Figure 3 shows the surface temperature distribution in the two cases at 12:15. In the current case, where the high-rise building shades the surrounding urban area, its shade extends 200 m toward the north. Because of the shade, the sidewalk (s1) surface temperature at 12:15 (Fig. 3) is 5 °C, which is 10 °C less than that of the removed case.

On the ground of the parking lot, the surface temperature is different at each spot that is shaded by the high-rise building. Such differences depend on the duration of the shading of the high-rise building. In the current case, the surface temperature of the east side of the parking lot (p1) is 5 °C lower than the rest. On the other hand, the surface temperature of the west side of the parking lot (p2) is greater than 10 °C because the asphalt pavement accumulates heat by solar radiation in the morning.

In some parking lot which is not shaded at 12:15, the cold accumulation owing to the morning solar shading remains on the ground. As a result, the surface temperature at 12:15 in the parking lot (p1) adjacent to the shaded area decreases by 5 °C compared with the removed case. The area where the surface temperature decreases owing to cold accumulation occupies approximately 25% of the parking lot (p1) area.

Mean radiant temperature distribution

Figure 4 shows the mean radiant temperature distribution and surface temperature distribution in the outdoor space shaded by the high-rise building. At the sidewalk (s1), the mean radiant temperature for the current case decreases by more than 15 °C compared with the removed case owing to shading and decrease in surface temperature. In the parking lots shaded by the high-rise building, the mean radiant temperature in the current case also decreases compared with the removed case. However, the mean radiant temperatures of the parking lots differ in the shaded area of current case and the difference is 7 °C. At point X, the mean radiant temperature is 0 °C, which is 7 °C lower than the air temperature.

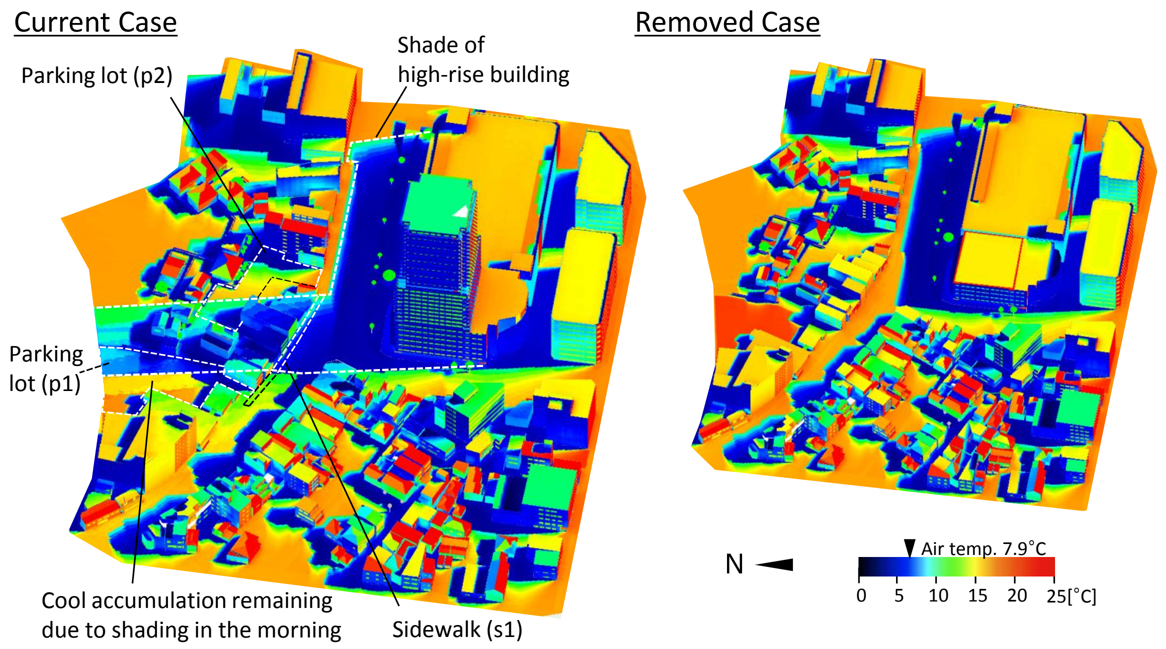

Figure 3 Surface temperature distributions at 12:15

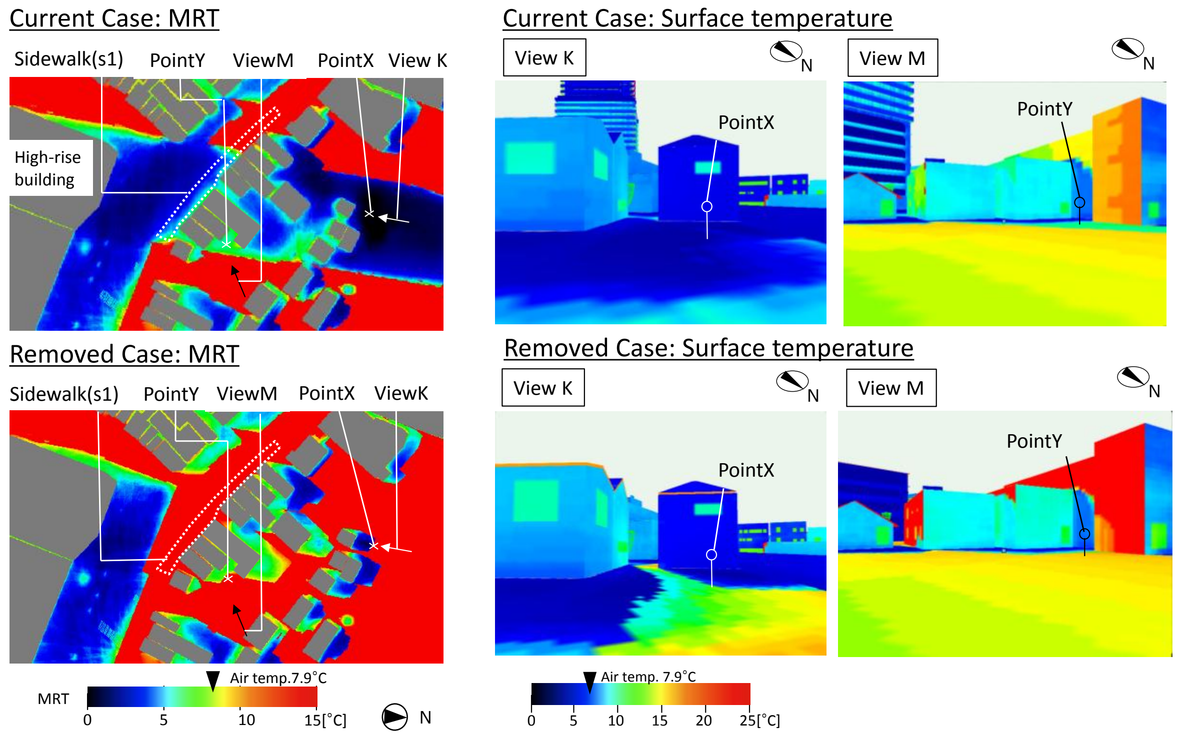

Figure 4 Mean radiant temperature distribution at 12:15 and at a height of 1.5 m, and surface temperature distribution at 12:15 in the outdoor space shaded by the high-rise building.

This is attributed to the ground that is shaded by the high-rise building and the surrounding buildings, and the building wall with low surface temperature (see View K in Fig. 4). On the other hand, at point Y, the ground surface temperature is more than 10 °C higher than that at point X, and the surrounding building wall keeps the surface temperature high owing to heat accumulation (see View M in Fig. 4). As a result, the mean radiant temperature at point Y of the current case is 7 °C higher than that at point X.

Effect on the building heat load

The relation between the daily solar radiation, which is received by the windows, and the heat load of each building is examined to demonstrate the effect of shading by the high-rise building. We focus on the building that is shaded by the high-rise building for more than 1 h and calculate the building heat load. Figure 5 shows the daily solar radiation distribution in each case and the increasing rate map of the building heat load. Figure 6 shows the diurnal change in the solar heat gain and heat load in the buildings. In this district, many buildings have large windows in the southern or eastern facades, which face the street in the north or west of the high-rise building. As shown in Fig. 5, in the building shaded by the high-rise building for more than 2 h, the daily solar radiation on the building southern facade is 5 MJ/day lower in the current case than in the removed case. Hence, these buildings with large windows increases by more than 30% in the heat load.

The shading effect on the building heat load depends on not only the distance from the high-rise building and but also the window location and site conditions. When the building is close to and has no windows facing the high-rise building, such as building (a), the rate of increase in the building heat load is within 5% despite being shaded by the high-rise building for more than 2 h.

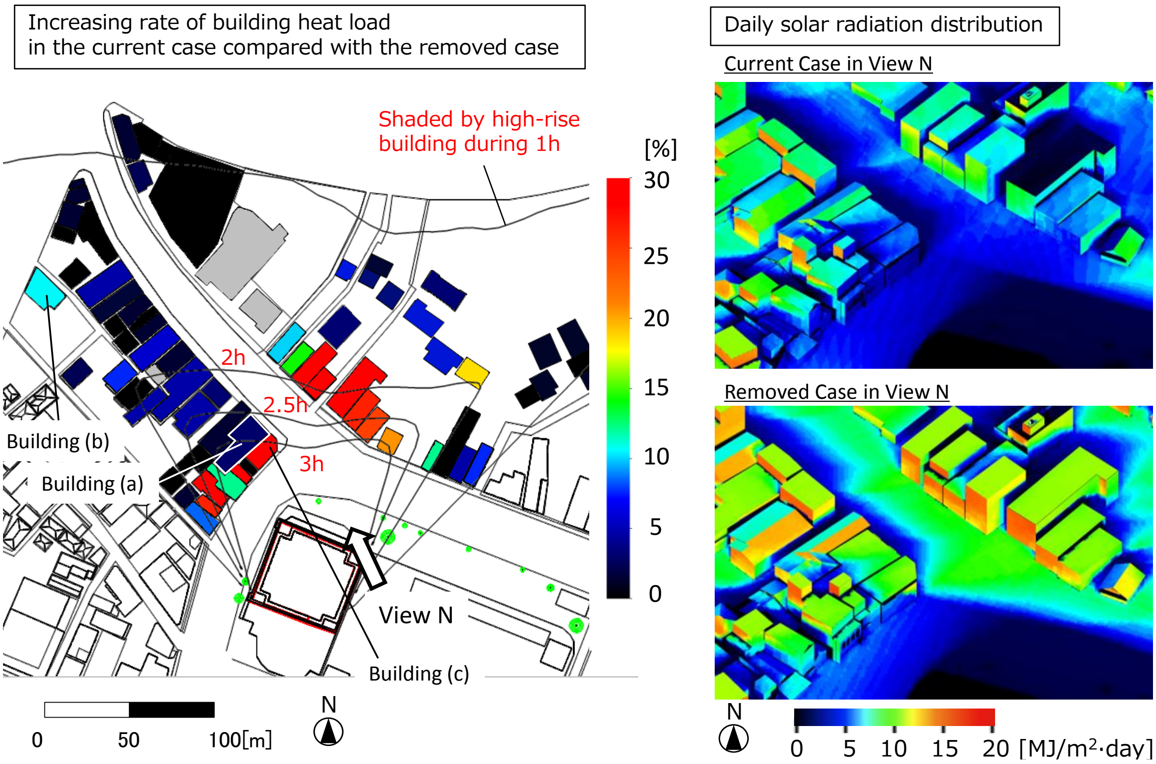

Figure 5 Increasing rate map of building heat load and daily solar radiation distribution in each case

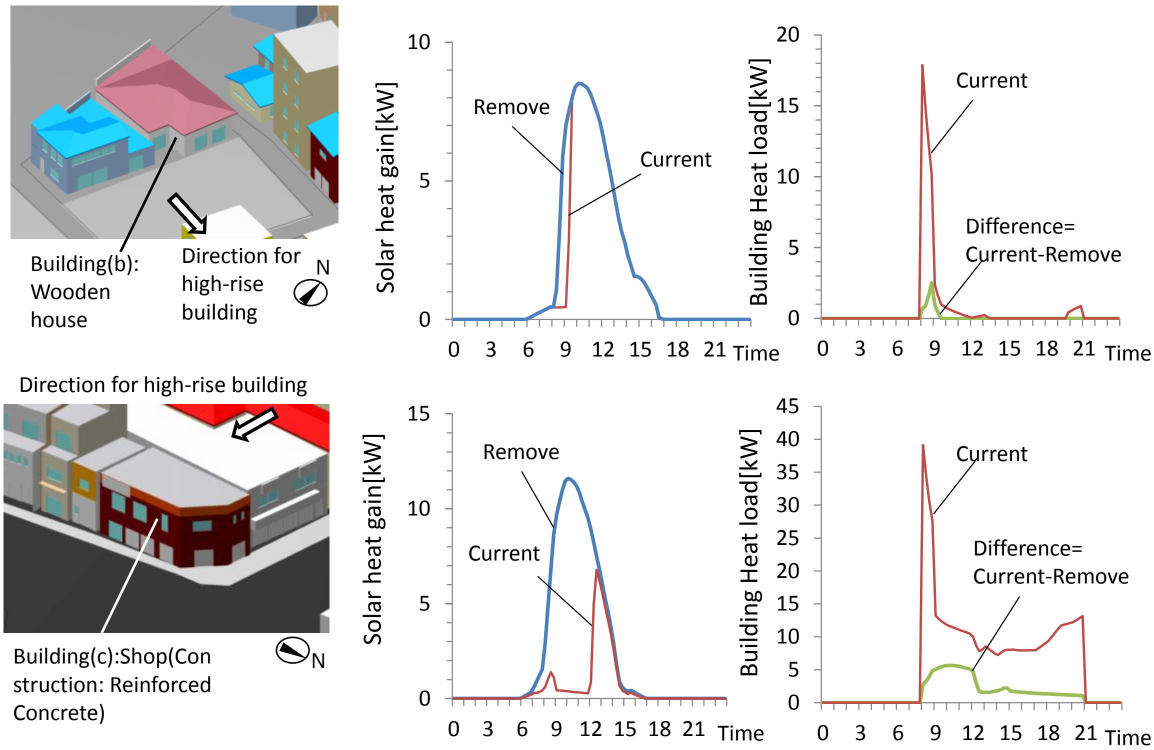

Figure 6 Diurnal change in the solar heat gain and building heat load in buildings (b),(c)

On the other hand, although building (b) is 170 m away from the high-rise building, the rate of increase in the building heat load is 10%. This is because building (b) has windows facing the high-rise building and the adjacent parking lot has no buildings or external objects as shown in Fig. 6.

In addition, different building materials are not affected in the same manner by shading. In reinforced concrete buildings, with large heat capacity, increasing building heat load is observed when shaded by the high-rise building as well as at other times. In building (c), the building heat load is larger than that in the removed case after the building is shaded. The building heat load of buiding (c) in each time from 1 p.m. to 8 p.m. is approximately 30% higher than that at 11 a.m., which is the time when the building is shaded.

CONCLUSION

The shading effect of a high-rise building on the thermal radiation environment in the outdoor space around it and the neighboring buildings heat load in winter is discussed and the following conclusions are reached.

- Shading effect by high-rise building at noon extends widely to the area apporoximately 200m away in the north and the lowest mean radinant temperature in the shaded area decreases 7 °C lower than air temperature. However, in the some space, the shading negative effect on the thermal radiation environment is mitigated by the surrounding space geometry and material. In particular, in the space close to the building wall and ground, which is heated because of solar heat accumulation in the morning, the mean radiant temperature keeps equal to the air temperature.
- In the target district, the northern and western street of high-rise building have many shops with southern or eastern façade with large windows, and these shops are affected more remarkably by high-rise building. The heat loads of these buildings are more than 30% larger than that in the removed case.
- Even for buildings 170 m away from the high-rise building, shading effect on the building heat load is not so little when the building is adjacent to the parking lot and has large window. In this condition, the building heat load increased by 10% compared with the removed case.

The following will be considered for our future work.

- Combine simulation with CFD simulation and study the wind and cold air distribution around the high-rise building.
- Perform simulations of the thermal environment in summer.

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NOMENCLATURE

I_d = Direct solar radiation on surface *i* [W/m^2]
I_{si} = Sky solar radiation on surface *i* [W/m^2]
I_{ri} = Reflective solar radiation on surface *i* [W/m^2]
L_{object_i} = Longwave radiation on surface *i* [W/m^2]
L_{sky_i} = Atmospheric radiation on surface *i* [W/m^2]
S_{human} = Surface area of the human body [m^2]
A_p = Effective radiation area (Underwood C. R. & Ward E. J., 1966) [m^2]
a_1 = Solar absorption of the human body [-]
a_2 = Emissivity of the human body [-]
W_i = Weighting factor [-]
σ = Stefan–Boltzmann coefficient [-]

Subscript

i = microcube surface (assuming human body)

Potential for Net Zero Energy Neighbourhoods in the Ahmedabad Urban and Solar Contexts

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ABSTRACT

Many net zero buildings have been proposed in different parts of the world. However, there is an argument that an individual building is not the right scale to develop Net Zero Energy Housing. The neighbourhood scale has the potential to integrate not only individual building systems, but also multi-building systems as well as of integrating neighbourhood geometry. This scale also offers opportunities for load sharing between buildings and diversity in functions. Inspite of India having a rich solar energy resource, there are no Net Zero Energy Neighbourhoods being developed. This paper tests the potential of three existing neighbourhoods in Ahmedabad, with different building typology and geometry, to achieve Net Zero Energy status by way of retrofitting Photovoltaic Technology. After a review of historical energy bills to assess the energy demand, the PVSyst software package (version 6.0) is used to test the potential performance of solar retrofits in the three different neighbourhoods. The results show that each of the three neighbourhoods can achieve Net Zero Energy status by retrofitting PV Panels. However, the investment cost and payback periods are prohibitive for the economic contexts of the three neighbourhoods. The paper further proposes neighbourhood scale retrofitting strategies. It also proposes government support policies, based on the neighbourhood scale, to overcome the cost limitations in achieving Net Zero Energy status.

INTRODUCTION

Carlisle, Geet and Pless (2009,4) define a Net-Zero Energy Neighbourhood, as "One that has greatly reduced energy needs though efficiency gains such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy". There are mainly two approaches to achieve a Net Zero Energy Neighbourhood. The first one is designing a neighbourhood considering environmental requirements and providing various technologies to balance the energy use and production. Another approach is providing system retrofits in existing neighbourhoods such that the energy produced by renewable sources is equal to the total energy used in the neighbourhood. Retrofit in building terminology usually refers to introducing new technology for a building to be more efficient. Keirstead and Shah (2013, 47) states that since buildings are long-lasting infrastructure, much of the existing building stock will need to be improved if short and medium-term energy efficiency and greenhouse gas reduction targets are to be met. In addition to the benefits achieved by retrofitting individual buildings, area-wide retrofit schemes can offer further benefits in terms of supply-side

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technologies, optimisation of area wide availability of renewable sources, economics of scale and project finances. However, financing of neighbourhood-scale and individual retrofits of renewables is currently expensive. Today, this technology is not widely applied due to high cost of implementation and long payback periods. Some examples of the neighbourhood approach include Masdar and Bedzed. Masdar in UAE is proposed as a carbon neutral city planned for 40,000 residents. It aims at sustaining 90% energy demand through Photovoltaic energy, while the rest will be sustained by other renewable sources. Although planned to achieve Net Zero Energy, the parts of it that have been executed have succeeded in some aspects but failed in others. Bedzed, designed as Britain's first net Zero Energy Community, also had failures which include its inability to use renewable resources for the combined heat and power plant; occupants behaviour of adding portable heaters resulting in higher than predicted energy consumption. This paper tests the potential of three existing neighbourhoods in Ahmedabad to achieve Net Zero Energy status by retrofitting PV Technology.The neighbourhoods have different housing typology and geometry.

SOLAR POTENTIAL OF AHMEDABAD FOR RETROFITTING PV PANELS

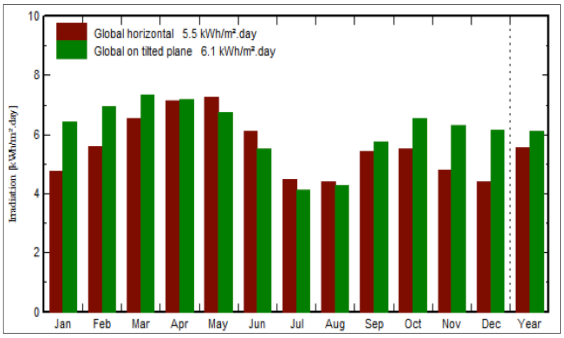

Fig. 1: Solar Irradiation in Ahmedabad based on Pvsyst software simulation. (Source: Authors)

In India, the solar radiation is abundant throughout the year; hence introducing solar photovoltaic technology in existing neighbourhood can reduce non-renewable energy demands. Ahmedabad is situated in the hot semi-arid climate zone of West India and is considered to have summer all year with average temperature of about 27^{o} C to 41^{o} C. It receives high solar radiation (Fig 1) especially in the south direction, hence has high potential for solar energy generation.

For testing the solar potential of the city to achieve a nZEN, a range of Neighbourhoods have been selected according to variation of housing typologies that exist in the city. The first neighbourhood type is the "POL" house – the traditional houses of Ahmedabad, consisting of a number of houses, facing the street and forming a cul-de-sac. Each house is connected to the street by a verandah (semi open space). This study is carried out in "Desai ni pol" situated on the eastern part of Ahmedabad. The second selected neighbourhood type is the apartment, which has grown rapidly in the city due to increased density and land prices. Many different kinds of apartments exist in the city ranging from low cost to luxury apartments with multiple Bedrooms. This study is carried out in Ambawadi apartments located in Western Ahmedabad, in a vicinity of mainly residences with few institution and commercial developments. The neighbourhood has six apartments with a large open space near the entry. Each apartment has three floor levels with four residences on each level. The third selected neighbourhood has the bungalow housing typology, which is spreading fast on the western side of the city due to ample availability of land. Many bungalows exist with large open spaces in the form of gardens with good potential to generate solar energy. However, shading is high in this neighbourhood due to trees. This study is carried out in Rushil bungalows located in western Ahmedabad near SG highway. The neighbourhood has 12 bungalows, each with a garden in the front and a covered backyard.

ENVIRONMENTAL CHARACTERISTICS OF THE SELECTID EXISTING NEIGHBOURHOODS

Pol: Each house has a deep long plot, sharing the longer wall with neighbouring houses, thereby reducing exposure to sun. Dense placements also offer mutual shading to the houses. The courtyard lets the hot air of the house to escape out and allows fresh air to enter. It also provides diffused light to the inner areas of the house. The tripartite windows maintain the inner temperature by allowing the cool breeze to enter and providing shade from direct sunlight. A rainwater-harvesting tank is also located below the central courtyard which helps cool the temperature of the courtyard.

Ambawadi Apartments: These apartments have low energy demand due to their orientation and planning. The periphery of the each floor has balconies, creating an offset for the main living spaces. Generous overhangs protect the houses from direct sunlight, keeping the houses cooler. Moreover each apartment block offers shading to the other block thereby reducing direct exposure of facades.

Rushil Bungalows: These bungalows have very few environmental considerations in their design. They have few openings with overhangs, providing shade from direct sun. However, most openings are not shaded, exposing the façade to direct solar radiation, and therefore heating the house fast in summer.

Fig 2: 3D Massing of the selected neighbourhoods of Pol Houses, Ambawadi apartments and Rushil bungalows respectively (Source: Authors)

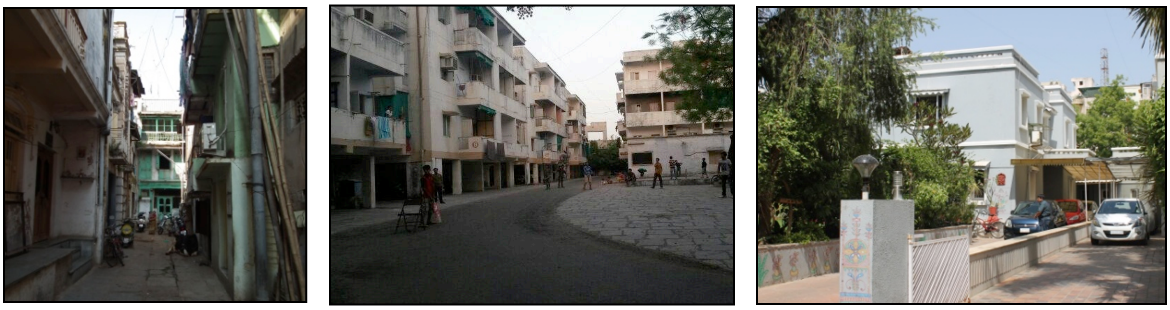

Fig 3:Photos of Pol Houses, Ambawadi apartments and Rushil bungalows respectively (Source: Authors)

For this study, seasonal variation of metered energy bills for selected houses in each neighbourhood was collected and averaged out to arrive at the energy used per household. The energy used per household was multiplied with the number of houses in the neighbourhood to arrive at the total energy used by the neighbourhood. Table 1 compares the energy consumed in each neighbourhood.

Table 1. Comparison of Energy Consumed [Pol (1), Ambawadi apartment (2), Rushil bungalow (3)]

	1	2	3
Energy / House / Month	270 kWh	525 kWh	1550 kWh
Number of Houses	32	72	12
Average number of Persons/House	6	4	4
Energy in Common Uses	-	-	825 kWh
Energy of Neighbourhood / Month	8640 kWh	37800 kWh	19,425 kWh
Energy of Neighbourhood / Year	103,680 kWh	4,53,600 kWh	2,33,100 kWh
Energy consumed per Person	540 kWh	1575 kWh	4856.25 kWh
Floor area / House	60 Sq. m	75 Sq. m	150 Sq. m

Table 1 shows that Neighbourhoods 1 and 2, which are low and middle income housing respectively, have less floor area and hence less energy used per person, when compared to Neighbourhood 3, which is upper middle class housing. Hence it could be concluded that energy used per person is greatly dependent on floor area of units and the lifestyle of residents in each Neighbourhood. From all three selected neighbourhoods, the Pol has the least energy consumed per person.

nZEN POTENTIAL: SOLAR ENERGY PRODUCTION AND COST

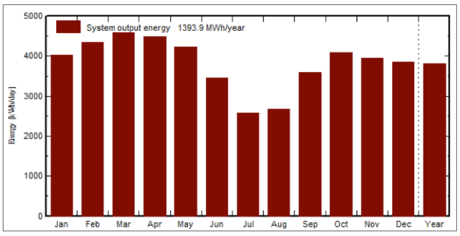

Fig 4 Annual Output of Desai Ni Pol by Pvsyst simulation. (Source: Authors)

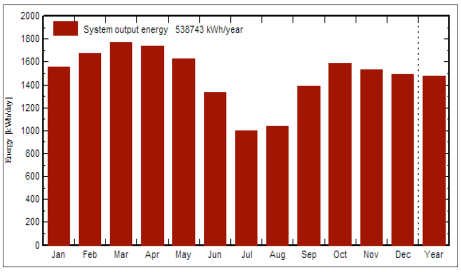

Fig 5 Annual Output of Ambawadi Apts. by Pvsyst simulation. (Source: Authors)

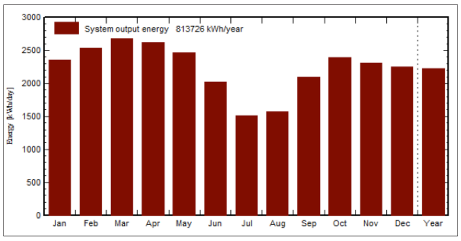

Fig 6. Annual Output of Rushil Bung. by Pvsyst simulation. (Source: Authors)

The shadow studies done in this research suggest that in the Pol house and Ambawadi apartments, the street and the space in between buildings respectively, remains shaded during most of the year, except for noon when the sun is overhead. Similarly in Rushil bungalows the open gardens and main access road remains shaded during most of the day by trees and vegetation.

Hence in all three neighbourhoods, the roof has maximum potential for direct as well as diffused solar radiation. In addition to the roof, the open space in Ambawadi apartments and open gardens and access road in Rushil bungalows have potential for direct and diffused solar radiation respectively. Hence in this study, roof area of all neighbourhoods is considered for solar energy generation.

Table 2 compares the energy produced using monocrystalline panels in each neighbourhood based on available roof area. It suggests that the Energy Produced/Year in Desai Ni Pol and Rushil bungalows, by using entire available roof area, is much more than the requirement of the entire neighbourhood. In Ambawadi apartments, the Energy Produced /Year is almost equal to the requirement of the entire neighbourhood. However, if energy demand increases in future, the neighbourhood can use its open spaces for solar energy production.

Table 2. Comparison of Solar Potential [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

	1	2	3
Roof Area Available	4916 Sq. m	1800 Sq. m	2900 Sq. m
Open Space	877.5 Sq. m	3335 Sq. m	4075 Sq. m
Plot Coverage	0.85	0.35	0.41
Energy Demand / Year	103,680 kWh	4,53,600 kWh	2,33,100 kWh
Energy Potential /Year (Generated from PVSyst)	14,75,212 kWh	5,40,151 kWh	8,70,243 kWh
Excess Energy Potential	13,71,532 kWh	86,551 kWh	6,37,143 kWh
Potential Output vs. Demand	14: 1	1.2: 1	3.7: 1
Energy Consumed /Person	540 kWh	1575 kWh	4856 kWh

Table 2 suggests that there is a direct relation between plot coverage and the excess energy produced - the lower the plot coverage (Neighbourhood 2 and 3), the lower the excess energy produced. The more compact the neighbourhood with higher plot coverage and less obstructions, the more the excess energy produced. With proper balance of these factors during the initial design stage, one can achieve nZEN. Table 2 also suggests that the full roof potential to produce solar energy for Desai ni pol, Ambawadi apartments and Rushil bungalows is 14, 1.2 and 3.7 times more than the present demand. Hence, all three neighbourhoods have potential to convert into nZEN as well as produce excess energy.

Similarly, Table 3 compares the investment cost of solar energy production in each neighbourhood. It suggests that in Desai ni pol, Ambawadi apartments and Rushil bungalows the cost that each household would pay annually to achieve nZEN is 2, 1.5 and 1.3 times respectively more compared to the current cost. Also, unit cost of energy increases in all neighbourhoods with retrofitting solar PV.

Table 3. Comparison of Investment and Loan as per Energy Demand of Neighbourhoods [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

	1	2	3
Present Yearly Cost/ Household	14,400 INR	31,200 INR	1,26,000 INR
Roof Area according to Energy Demand	346 Sq. m.	1515 Sq. m.	780 Sq. m.
Module Cost	33,95,561 INR	122,44,109 INR	63,03,898 INR
Support Cost	25,96,605 INR	113,69,530 INR	58,53,619 INR
Inverter and Wiring	7,98,956 INR	34,98,317 INR	18,01,114 INR
Transport and Mounting	37,04,577 INR	120,72,796 INR	70,98,285 INR
Total Investment /Neighbourhood	104,95,699 INR	391,84,752 INR	210,56,916 INR
Payback Period	22.7 Yrs.	17.4 Yrs.	13.9 Yrs.
Yearly Cost for Neighbourhood after Loan	10,39,780 INR	37,88,168 INR	20,68,237 INR
Yearly Cost/ Household upto 20 Yrs.	32,493 INR	52,613 INR	1,72,353 INR
Unit Cost	10.01 INR/ kWh	8.33 INR/kWh	8.84 INR/kWh

NET ZERO ENERGY BUILDING (nZEB) VS NET ZERO ENERGY NEIGHBOURHOOD (nZEN); COST AND CHALLENGES

Table 4 compares the nZEN approach versus the nZEB approach with respect to cost limitations and the potential energy generation through solar panel retrofits. It shows that taking a neighbourhood approach is much more advantageous, as it provides availability of more shared renewable resources on site and energy sharing between houses thus helping to achieve Net Zero Energy. It provides more solar access with availability of multiple rooftops and common spaces including open space and streets, when compared to individual buildings, hence providing more unshaded potential area for PV installation. The unit cost of energy is also lower in nZEN approach compared to the nZEB.

Table 4. Comparison of Grid Connected nZEB vs. nZEN: Energy Output vs. Cost [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

	1	2	3
Annual Energy Demand / Building	3,240 kWh	75,600 kWh	18,600 kWh
Present Annual Cost / Building	14,400 INR/Yr.	3,74,400 INR/Yr.	1,26,000 INR/Yr
Yearly Investment for nZEB (PVSyst)	50,398 INR/Yr.	7,80,690 INR/Yr.	2,34,137 INR/Yr
Yearly Investment for nZEN/ Building	32,493 INR/Yr.	6,31,361 INR/Yr.	1,72,353 INR/Yr
Unit Cost For nZEB	15.55 INR/kWh	10.33 INR/kWh	12.59 INR/kWh
Unit Cost For nZEN	10.01 INR/kWh	8.33 INR/kWh	8.84 INR/kWh

Table 5: Stand Alone Systems for Individual Buildings Based on Annual Energy Required [Pol (1), Ambawadi Apt (2), Rushil Bungalows (3)]

Infrastructure	1	2	3
Module Cost	1,62,899 INR	3,10,813 INR	7,75,776 INR
Battery Cost	4,73,709 INR	9,04,122 INR	26,43,603 INR
Regulator Cost	82,911 INR	1,30,322 INR	2,77,008 INR
Transport/Fitting	6,21,833 INR	9,77,418 INR	20,77,560 INR
Total Investment	13,41,353 INR	23,22,676 INR	57,73,947 INR
Annuities	1,07,634 INR/Yr	1,86,378 INR/Yr	4,63,316 INR/Yr
Maintenance Cost	1,18,427 INR/Yr	2,26,031 INR/Yr	6,60,901 INR/Yr
Total Yearly Cost/ Household	2,26,061 INR/Yr	4,12,408 INR/Yr	11,24,217 INR/Yr
Unit Cost	69.99 INR/kWh	66.90 INR/kWh	62.27 INR/kWh

Comparing the cost of Stand-alone nZEB (Table 5) with Grid connected Neighbourhood scale retrofits (Table 3); nZEN turns out to be more economically viable. The cost that each household ends up paying annually for a Stand-alone nZEB is about 7-10 times more than that required for an nZEN. This reduced cost in the neighbourhood approach happens because of sharing of infrastructure required for connecting the system to the Grid. The cost of batteries required for storage of excess energy, transport and maintenance is high, as required in Stand-alone systems, acting as a major barrier for nZEB.

Barriers and Challenges

Though connecting to the grid offers incentives of using electricity all year round and selling the excess energy, in India, it faces a few challenges. For an owner, a single point of contact from financing, to operation and maintenance is required for solar PV to be more prominent. However, presence of multiple partners forms a major barrier. Similarly, there might be a problem of ownership in shared rooftops and long-term leasing for solar power generation due to fixed incentives. Moreover, the connection of multiple PV systems to the grid might also have stability issues, hence making it vital to monitor it to avoid its collapse. Also monitoring of energy being fed into the grid to avoid misuses is important. Power generated from other sources if fed into the grid, can lead to a collapse of the feed-in-tariff model. Likewise, availability of different types of devices of diverse quality, for net metering, creates a barrier for precise measure. Hence, establishing a "star rating system" for devices is fundamental for its success.
According to the Technology Strategy Board in UK, neighbourhood retrofits also face challenges due to lack of awareness amongst owners about sustainability and long term gains. The biggest challenge to realise this approach is reaching a mutual agreement amongst families within the neighbourhood regarding investing in this technology. Moreover, lack of competition, choice and availability of materials, higher than expected cost are other challenges making it difficult to implement this technology.

COMPARISON OF USING ALTERNATIVE PANEL TYPES

In order to overcome the cost limitation, since monocrystalline panels are the most expensive PV panel, using different panel types might be a useful option for these neighbourhoods to attain Net Zero Energy. Table 6 suggests that in Pol houses and Rushil bungalow, the amount of energy produced by Polycrystalline and Hybrid Panels is enough to meet demand. However, Table 7 indicates that the cost difference is not sufficient when compared to Monocrystalline panels. The cost of energy per unit also increases by using a less efficient panel. Hence, though using an alternate panel type limits the excess energy produced, the cost of its realisation is more compared to the current cost of the neighbourhood.

Table 6: Comparison of Energy Potential by using Alternative Panel types on entire roof area available [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

Panel Type	1:Energy Output	2:Energy Output	3:Energy Output
Energy Demand	1,03,680 kWh	4,53,600 kWh	2,33,100 kWh
Monocrystalline	14,75,212 kWh	5,40,151 kWh	8,70,243 kWh
Polycrystalline	13,83,012 kWh	5,06,392 kWh	8,15,853 kWh
Hybrid	9,22,008 kWh	3,37,594 kWh	5,43,902 kWh

Table 7: Comparison of Unit Cost (INR/kWh) and Yearly Cost (INR/Yr.) using Different Panel Types on entire Roof area Available [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

Panel Type	1: INR/ Yr.	1: INR/ kWh	2: INR/Yr.	2: INR/ kWh	3: INR/Yr.	3: INR/ kWh
Present Cost	-	2.8 - 4.3	-	2.8 - 4.3	-	2.8 - 4.3
Monocrystalline	111,94,544	7.59	43,10,750	7.98	66,73,778	7.67
Polycrystalline	107,87,085	7.80	41,44,648	8.18	64,19,822	7.87
Hybrid	87,02,963	9.44	32,92,894	9.75	51,18,930	9.41

SOLUTIONS FOR OVERCOMING COST LIMITATIONS

In order to overcome the cost limitations, an important step would be to reduce energy demand by increasing the efficiency of building envelope. Provision of shading devices for openings and use of better insulating materials in walls and roof would help decrease the overall demand of the three neighbourhoods. In addition, provision of neighbourhood scale retrofits like using efficient streetlights, offering better transportation networks, reducing energy required in pumping ground water, etc. would further help reduce the energy demand of the neighbourhood. After reducing the demand, below are few other ways, which would help overcome the cost limitations of neighbourhood retrofits.

1) Selling the Excess energy to the Government

In each of the three Neighbourhoods, the roof area available has potential to produce excess energy. If the excess energy could be fed into the grid and sold to the government, the payback period and cost could be reduced to a large extent. The State already has a number of privately owned power plants, which sell energy to the state government. According to the Gujarat Electricity Regulatory Commission (GERC) the current rate of buying solar power for all PV Plants commissioned between 1st April 2014 to 31st March 2015 is reduced to 8.03 INR. If each of these neighbourhoods sells their excess energy to the government at the given rate, the yearly instalment would reduce to a large extent. For example in the Pol, yearly instalment on the loan, for the demand energy roof area, would be 32,493 INR. However, after entire roof area installation and selling of excess of energy the neighbourhood has to pay 5660 INR/Yr. (Table 8). Table 8 shows the reduced price that each neighbourhood has to pay after selling excess energy to the government. Hence, in this way major part of the investment amount could be borne by the government, while the residents could pay the remaining amount. However, there are some barriers in this approach – the main one being convincing the government to invest in the neighbourhoods.

Table 8: Selling Excess Energy to the Government [Pol (1), Ambawadi Apts (2), Rushil Bunglows (3)]

	1	2	3
Annual Excess Energy	13,71,532 kWh	86,551 kWh	6,37,143 kWh
Money Received by selling Annual Excess Energy at Rs 8.03/kWh	110,13,401 INR/Yr.	6,95,004 INR/Yr.	51,16,258 INR/Yr.
Yearly Cost / Neighbourhood	111,94,544 INR/Yr.	43,10,750 INR/Yr.	66,73,778 INR/Yr.
Yearly Cost/ Neighbourhood (After selling Excess Energy)	1,81,143 INR/Yr.	36,15,746 INR/Yr.	15,57,520 INR/Yr.
Yearly Cost/ Household (After selling Excess Energy)	5660 INR	50,218 INR	1,29,793 INR
Present Yearly Cost/ Household	14,400 INR	31,200 INR	1,26,000 INR

2) Public Private and Neighbourhood Partnership

Currently few retrofitting strategies have been established in India to promote solar power generation in the domestic context. In Gujarat, the city of Gandhinagar has been promoted as the first solar city, where they aim to produce 5MW of energy through public and private rooftops. The city has tried the Public Private Partnership concept, wherein the private developers would be given access to rooftops of 25 public buildings and around 250 private houses. City dwellers would be given a "green incentive" of INR 3/kWh of energy produced on their privately owned rooftops after Solar PV installations. This serves as a useful strategy of combining private and public investors to invest in solar power generation on local rooftops. However, since this strategy is limited to individual buildings, the roof area available is less giving no neighbourhoods scale energy benefits to house owners. Regarding neighbourhood scale retrofitting strategies, this approach should prioritise installations at the neighbourhood rooftops that are most exposed to solar radiation and should distribute such solar exposure benefits to all dwellings across the neighbourhood. A phased installation approach would potentially help low-income dwellers to distribute capital installation costs for longer periods, thus reducing their monthly repayments.

3) Government Policies, Initiatives and Incentives

Many countries have tried to promote and fund retrofits within the government policies. For example, the UK Government's "Green Deal plan" is a financing mechanism that allows consumers to repay through saving on energy bills for energy saving home installations. Even within India, the Jawaharlal Nehru Nation Solar Mission is an important initiative by the government to promote solar power wherein it targets at producing 20,000 MW of grid connected solar power by 2022. Under the mission, private companies are offered incentives to invest in solar power, by reducing customs duty on solar PV by 5% and exempting excise duty on Solar PV. This is expected to reduce the overall cost of a rooftop solar panel installation by 15–20%. The government also provides Generation based incentives (GBI) and 80% accelerated depreciation income tax benefits on solar energy production. Moreover, the Ministry of New and Renewable Energy (MNRE) in India provides 30% subsidy on the cost of installation of solar PV power plant in all states. However, existing policies target large-scale production of solar power plants and not the domestic sector. Hence, more policies are required, targeting urban neighbourhoods, providing incentives directly to the residents, and helping them achieve Net Zero Energy.

CONCLUSIONS

From the research, it can be concluded that all three neighbourhoods in Ahmedabad have immense potential to produce solar energy and achieve nZEN status. This paper has tested the initial potential of the neighbourhoods and provided rough estimates of investment. The key limitation of this technology is the cost factor and methods have been suggested to overcome this within the solar and economic context of Ahmedabad. With a proper mix of environmental considerations at a design stage- considering orientation, plot coverage and density of a neighbourhood, the energy demand can be restricted. This, followed by government support to implement this technology, by either buying excess power from local neighbourhoods instead of private power plants, or by offering incentives to private and public investors for investing in it at the neighbourhood scale, would help each of these urban neighbourhoods in Ahmedabad to achieve Net Zero Energy. The work suggests that further research is needed to explore links between plot coverage and solar energy in Ahmedabad in order to inform policy on neighbourhood planning to benefit from the conflicting requirements of solar exposure and shading. Further work is also needed on cost reduction strategies to make solar PV more accessible to low income neighbourhoods.

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Bioclimatic architecture as an opportunity for developing countries

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ABSTRACT

The proper adjustment of the architecture to the climate is one of the basic characteristics of vernacular building. Nowadays this area received an important support through the application of cutting-edge technology. Still, despite the clearly visible change of attitudes towards nature, more detailed analysis often lead to the conclusion that the arising buildings are very rarely based on extensive studies of local bioclimatic conditions. The purpose of this paper is to discuss how the traditional ways of adapting dwellings to the climate are combined with advanced technology and applied in contemporary bioclimatic buildings. Three important case studies are briefly presented in order to demonstrate that the relevant distinguishing feature of bioclimatic architecture is to go beyond the scheme of low-energy buildings, constructed from renewable materials and meeting the conditions of sustainable development certification systems. It is much more vital for the true green design to implement the structures in the ecosystem in such a way that they become an integral part of it. Thus understood bioclimatic architecture is logical, well adapted to the climate and therefore also economical. It creates great opportunities and should be perceived as the solution for the developing countries (as well as for the whole world).

INTRODUCTION

The idea of bioclimatic architecture is closely related to the proper adjustment of the dwelling to the climate. That is also one of the characteristics of vernacular building, based on the traditional ways of adapting architecture to the specific climatic conditions. Vernacular architecture is directly linked to the available resources that influence building techniques (Balbo, 2013, p.37). Furthermore, it is customized to the functional needs and cultural background of the inhabitants. The main difference between vernacular and bioclimatic building lies in the ability to select the technological solution most appropriate to the climate. In traditional architecture that kind of knowledge has been naturally transferred from one generation to another. In bioclimatic building the concept of architecture optimally adapted to the local conditions received an important support through the application of advanced technologies. Due to the combination of traditional climatic solutions and cutting-edge technology, bioclimatic dwelling is well suited to the needs of the contemporary user. The other difference involves proper understanding of complexity and sensitiveness of the natural environment. Bioclimatic architecture is based on holistic approach, including in-depth environmental analysis. Ultimately, the bioclimatic building should become an integral part of the ecosystem and ensure the symbiosis between the cultural and natural processes. However, despite clearly visible change of attitudes towards nature, the alarming datum is that more detailed analysis of projects often lead to the conclusion that although the idea of so-called sustainable design is manifested all over the world, in fact, the arising edifices are

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rarely based on extensive studies of bioclimatic conditions as the wider aspect of the problem is sometimes simplified (or even ignored) within the design process oriented towards the energy certification achievement (e.g. Telles, 2012).

Analysis of the various solutions, used in similar climatic conditions, combined with the application of contemporary knowledge allows to develop and to implement technologies that will help to customize the newly erected buildings to the requirements of the modern user. Two biggest challenges in this area are connected with the indoor climate and lighting (McIntyre, 1980; Mahdavi, 1996). Adequate lighting of the interiors with the use of daylight not only positively affects the user comfort, but also has a significant impact on reducing electricity consumption. Although this aspect is considered by the designers more often than the natural cooling, the proper use of daylighting should be further promoted.

The necessary factors of the comfortable indoor microclimate are: thermal comfort, proper air humidity, adequate air exchange rate, the correct oxygen content (this parameter can be improved for example by the introduction of green plants inside the building) etc. In most of developing countries the challenges of thermal comfort derive from the necessity of cooling the indoor air. Despite many criticism, the plant air conditioning systems are so widespread that they are most frequently applied in purpose to provide low temperature and low humidity in the buildings (Mahdavi, 1996). That kind of cooling is commonly used, especially in the offices, retail spaces or public buildings, regardless the high costs, electricity consumption, environmental impact and without considering the application of natural systems, based on local bioclimatic conditions. In many cases the only difference between conventional and so-called sustainable building is limited to the fact a part of electric energy for air conditioning systems comes from photovoltaic panels or other renewable sources.

NATURAL VENTILATION SYSTEMS IN HOT CLIMATE

Cooling systems in vernacular architecture in hot climate zones are based on natural ventilation. Among various schedules observed in traditional dwellings there are three basic models distinguished by Sørensen, that may be applied in contemporary bioclimatic architecture (Sørensen, 2008). These are:

1. Cross ventilation based on the pressure difference across the building shown in **Figure 1a**.
2. Chimney ventilation based on the stack effect i.e. underpressure caused by the rising hot air shown in **Figure 1b**.
3. The wind catchers and wind towers based on overpressure and underpressure presented in **Figure 1c**.

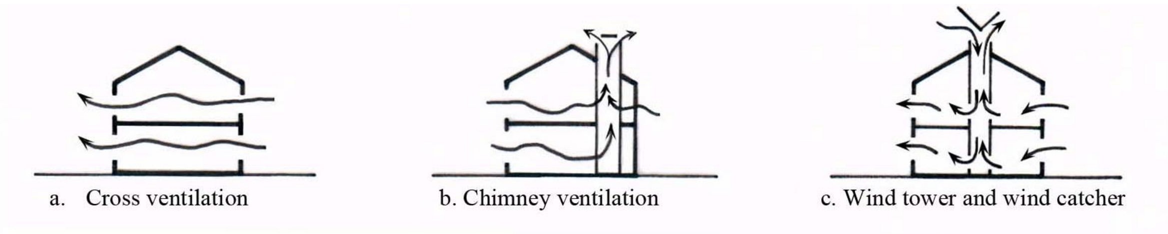

Figure 1 Basic models of natural ventilation. Based on Sørensen (Sørensen, 2008).

In many regions some modifications improve these basic systems. In hot and humid regions, e.g. in Thailand, many traditional houses are openwork and built on high stilts, so that the cross ventilation is combined with the elevated floor as described by Tantasavasdi and presented in **Figure 2** (Tantasavasdi et al., 2001; Tantasavasdi et al., 2007). In Japan, where the temperatures are lower, the floor is slightly raised above the ground. In both cases the air flows under the building to cool it in summer and – in case of the Japanese house – to separate it from the ground in winter. Also in both dwelling types the roof drainage systems (made of natural materials) allow for collecting rainwater.

Different solutions may be observed in hot and dry climatic conditions of Arab countries where the wind towers and wind catchers are quite common. They may be additionally combined with simple but effective evaporative cooling systems described by Hassan Fathy (Fathy 1986) as shown in **Figure 3**. On the basis of these solutions some holistic concepts for bioclimatic architecture were created. The leading architectural workshops in this area are Mario Cucinella Architects (MCA) and TR Hamzah & Yeang.

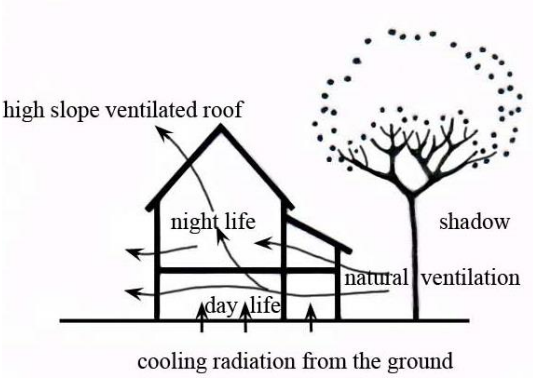

Figure 2 Natural cooling in Thailand. Based on Tantasavasdi (Tantasavasdi 2001).

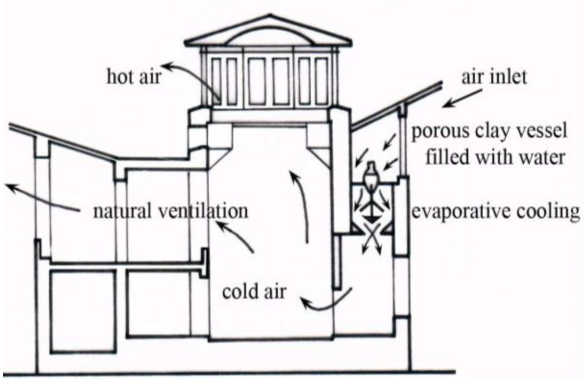

Figure 3 Evaporative air cooling system in Egypt. Based on Fathy (Fathy 1986).

ENVIRONMENTAL STRATEGIES IN THE CENTRE FOR SUSTAINABLE ENERGY TECHNOLOGIES (CSET) DESIGNED BY MCA

Centre for Sustainable Energy Technologies (2006-2008, Ningbo, China) was designed by Mario Cucinella Architects in cooperation with School of the Built Environment, University of Nottingham. The edifice is located in the Nottingham University new campus in Ningbo and it is dedicated to "(…) the diffusion of sustainable technology including solar power, photovoltaic energy, wind power and so forth" (Giorgi, 2006, p.90). The building itself represents advanced environmental strategies developed in direct relation to the local context. A very interesting hybrid system was applied in the project. It is based on the knowledge gleaned from vernacular architecture of hot climate areas (both dry and humid) and successfully combined with high-tech, environmentally safe technology. The non-conventional air-conditioning systems are supported with the cutting-edge technologies for the exploitation of renewable energy sources. The project was created with an intention to take the maximum advantage of the local bioclimatic conditions and to minimize the environmental impact of the building. Following the results of the local climate analysis, the designers developed the structure that allows to reduce the energy demand for heating in winter and cooling in summer. During the intermediate seasons (spring and autumn) the natural ventilation, triggered by a series of automated openings, provides comfortable temperatures and humidity, so there is no need to use plant air conditioning systems. Regarding the climatic conditions it was essential to establish the proper thermal insulation and create massive structures with high thermal capacity. The crucial part of the heating and cooling concept was the carefully controlled air movement within the building.

In hot and humid summer the passive cooling strategies are applied. Thereby the usage of plant systems is significantly diminished and limited only to the hottest days. During the warm part of the year the layer of the ground, located below the land surface, is colder then air. The incoming air is pre-cooled naturally when passing through the earth-to-air heat exchanger constructed in the form of a series of pipes buried in the ground as shown in **Figure 4**. Subsequently the air is further cooled and dehumidified by the air handling unit (AHU). Similarly the ventilation air coming through the air inlet in the tower is cooled and dehumidified by the AHU placed in a coverage. A solar chiller that pre-cools the external air for the tower ventilation is powered by hot water from solar tubes. Thus prepared air is distributed throughout the building. The chimney effect fastens the air exchange and the warm air is removed through the windows placed in the double skin south façade.

High thermal inertia of the green roof in the lower part of the building prevents overheating while thermal mass of the concrete surfaces supports the coolness distribution. The geothermal heat pump produces cold water for cooling the concrete floors. The radiant cooling from the ceilings is effective and healthy so that the mechanical cooling is required exclusively for pre-cooling the incoming ventilation air. In such a way the correct passive cooling design of the building and the high inertia of its concrete structure provide optimal indoor microclimate during summer.

The angles and materials of the southern part of the building were designed to pre-heat ventilation air in winter. The external air inlets are located on the ground level, at the bottom of the double skin façade so that during sunny days the air is naturally heated by the passive solar gains. After reaching the appropriate temperature the air is distributed in the edifice. Other air inlets are situated in the ground, outside the building. The incoming air is pre-heated by the earth-to-air heat exchanger. Further heating is provided by the geothermal heat pump, which is powered by energy from the photovoltaic panels. The air heating system is integrated with the radiant air-conditioning ceiling. The radiating coils embedded in the floors are activated when it is necessary to heat ventilation air. The heat is stored by the concrete ceiling slabs and released gradually to provide proper thermal comfort during the day. The northern façade is well insulated to avoid heat loss during the cold season of the year. The heat transfer coefficient of the opaque walls is 0,25 W/m²K and of transparent parts 1,2 W/m²K.

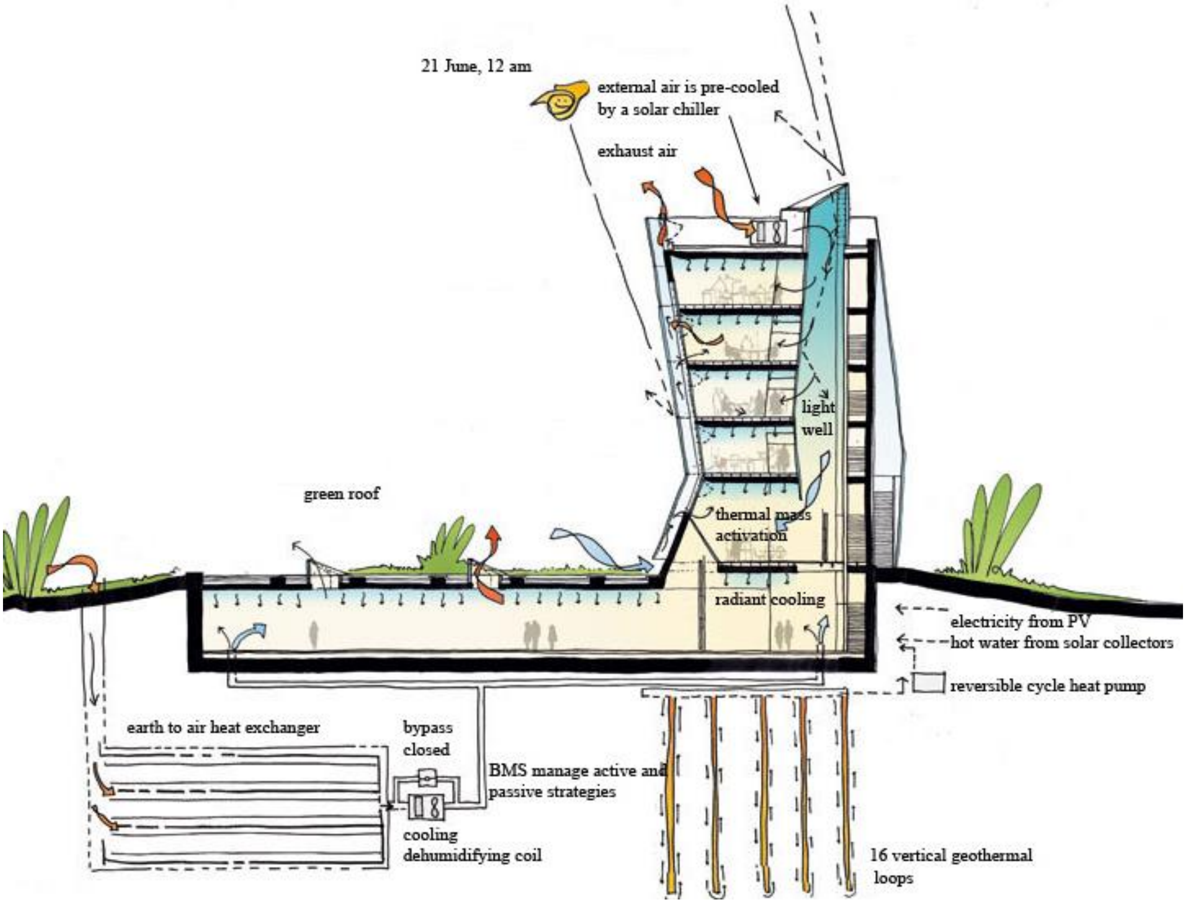

Figure 3 Centre for Sustainable Energy Technologies (CSET, 2006-2008, Ningbo, China) by MCA, environmental strategies – summer. Drawing © MCA.

The whole building envelope was designed in favor to provide maximum usage of natural light as it was possible without glare and overheating during summer. Such solution reduces the use of artificial lighting and thus also the electric energy consumption. All the necessary artificial lighting systems are characterized by high luminous efficiency and low power consumption. Electricity, required to power that lighting as well as the office equipment, comes from especially redesigned photovoltaic system. The energy surplus produced during maximum solar radiation periods can be stored in batteries or sold to the nearby sports center. The BEMS (Building Energy Management System) controls the building operation and manages active and passive systems to optimize comfort level, while reducing energy consumption.

All the environmental strategies were chosen in purpose to create contemporary bioclimatic building that provides proper balance between local climate factors (sun angle, air and earth temperature in different seasons, wind, humidity), ecosystem (plants and species of the area), technology (including renewable energy sources) and the occupant needs (indoor comfort, reference to Chinese culture). The educational value of the project is connected with promotion of the concept of bioclimatic architecture that derives from the environmental studies and therefore is very well adapted to the natural and cultural context.

BIOCLIMATIC ARCHITECTURE AND ECOSYSTEMS

It should be noted that while sustainable development program in architecture strongly accentuates local aspects, under the label of sustainable architecture there is often an attempt to create a global golden rule of architecture. The evaluation methods are inherently characterized by some averaging, but the creation of the built environment truly adapted to the bioclimatic conditions requires an individual approach. Conducting environmental analysis is necessary each time for the specific location. Moreover, due to dynamic nature of ecosystems, analyses should be repeated and changes monitored (Yeang, 1996). Increased attention is given to the relationship between the architecture and the ecosystem (Hart, 2011). Ken Yeang, one of the most important creators and promoters of bioclimatic architecture, notes the necessity of integration of the following Eco Infrastructures:

1. Green **-** connected with natural habitats and the environmental biodiversity.
2. Gray **-** related to engineering that include sustainable energy and technologies oriented towards low environmental impact as well as zero CO_2 emissions.
3. Blue **-** concerning water management, rainwater harvesting and gray water recycling.
4. Red **-** referring to human culture i.e. law regulations, social norms and habits, user comfort, standard expectancy, materials as well as the human impact on the environment.

Each part of infrastructures described above is analyzed and developed in close relation to the existing ecosystem, with the intention to restore, preserve and enrich its equilibrium and biodiversity. Proper implementation of that strategy into the bioclimatic design leads to the authentic adaptation of architecture to the local context. Thus created holistic approach is an important distinguishing feature of bioclimatic architecture.

RELATION TO THE ECOSYSTEM ON THE EXAMPLE OF SOLARIS BUILDING DESIGNED BY TR HAMZAH & YEANG

Holistic and consequent approach to bioclimatic architecture can be observed in Solaris (2011, Singapore,) designed by TR Hamzah & Yeang. This 79-meters high structure is situated in Fusionopolis, in the area of the former military base which now became a fast developing business and research area of Singapore. Since the existing ecosystem was seriously damaged, one of the main goals of the architects was to restore and enrich its biodiversity in purpose to create equilibrium of the natural and built environment. Therefore the continuous perimeter ramp, with a length of 1500 meters, was designed to introduce maximum amount of green area into the building. The landscaped ramp established the link between One-north Park that reaches directly the building façade and Solaris towers. The higher tower has 15 and the lower 9 floors. Both of them house research facilities and offices. All the areas of the building are connected to the spiral ramp and passively ventilated atrium. The service path that goes through the ramp provides direct access for plants maintenance and is used as the linear park that leads up to the roof gardens on the top of each tower. This continuous landscaped spiral with a minimum width of 3 meters was designed for the benefit of the environment, as it enables fluid movement of small organisms between green areas of the edifice and thus contributes to biodiversity and health of the ecosystem. At the building corners the ramp expands to the terraces. As a consequence total landscaped area of the project covers 8,363 m^2, with the site area 7,734 m^2. That results with 108% ratio of landscape to site area and 95% of the landscaped area located above the ground level.

Bioclimatic concept combines traditional solutions developed for hot and humid climate zones with the most contemporary technology and knowledge. The climate-responsive façade design is based on studies of local climatic conditions, including the sun-path analysis. The specific building location at the equator and the east-west sun-path affected specific requirements of the façade shading. The first element of this strategy is the ramp with deep overhangs and the abundance of shade plants. The second solution in favor of the ambient cooling are the sunshade louvers with shape and depth determined directly by the solar-path analysis. The louvers and the green ramp created a pleasant buffer space which significantly reduced solar gains and glares. Consequently the heat transfer through the low-e double-glazed façades was also considerably decreased. The external thermal transfer value (ETTV) of the whole system is 39 W/m^2.

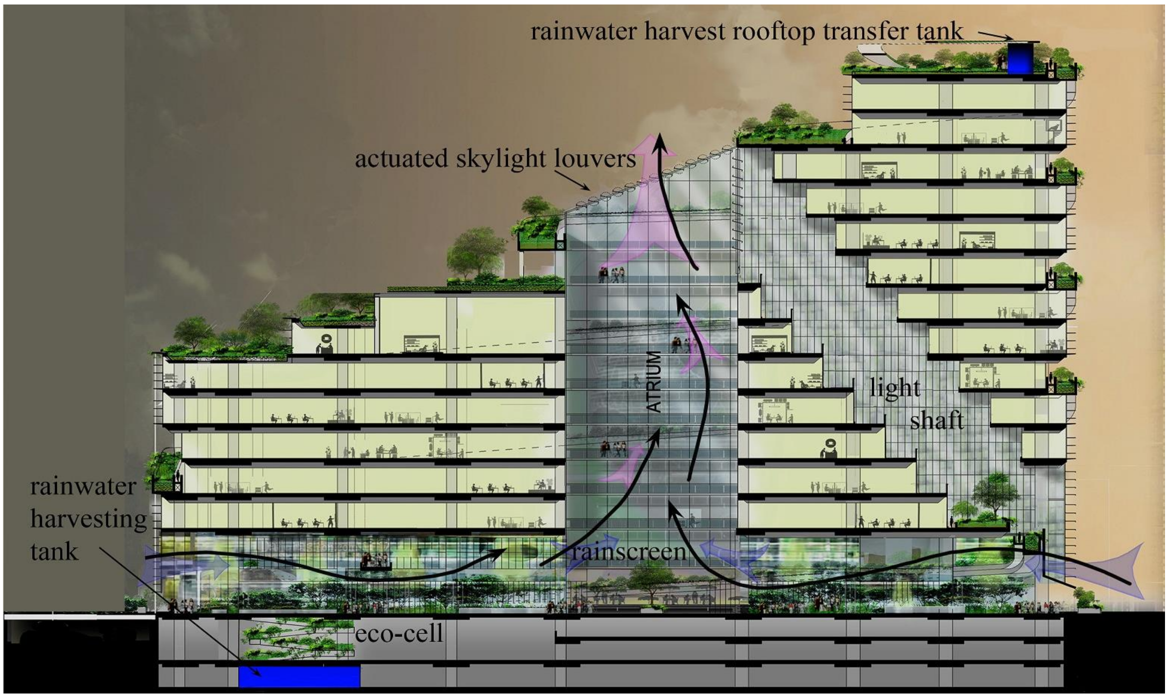

Figure 4 Solaris (2011, Singapore), by TR Hamzah & Yeang, bioclimatic section. © TR Hamzah & Yeang.

An atrium situated between the two towers is fully passively cooled and supports natural ventilation and daylight distribution within the internal areas of the building. An operable glass-louvered skylight system was installed on the roof over the atrium to enable stack effect cooling. Computational Fluid Dynamics (CFD) simulations were carried out to provide optimal thermal comfort with the controlled air flow in the atrium. Simultaneously, the active energy use was diminished. Both the louvers and the rainscreen walls are controlled by climate-responsive sensors to ensure protection against the precipitation and to allow natural ventilation during the rain. The atrium is directly connected to the landscaped area on the ground floor, linked to One-north Park which allows for cross ventilation. In order to provide optimal daylight penetration within the building's interior, the diagonal solar shaft was designed. It crosses the structure from the top of the higher tower down to the street level. The solar shaft gained more attractiveness with the landscaped terraces situated inside. Additional daylight is received from the façade shading louvers that create also double light-shelves and redirect the light into the building. To optimize the system performance a series of sensors measure the illumination level. When the sensors register a sufficient amount of daylight, the artificial lighting is automatically switched off. Thereby the energy consumption is reduced. As pointed out by Council on Tall Buildings and Urban Habitat (CTBUH), the reduction in overall energy consumption in Solaris building reached 36% compared to relevant precedents (CTBUH, 2012).

Due to the large amounts of vegetation located within the building, it was necessary to solve the problem of irrigation in an efficient and environmentally safe way. Based on the concept of bioclimatic design the attention was focused on the high average of rainfall in the area. Consequently a large-scale rainwater recycling system was proposed. Rainwater is harvested on the roof via symphonic drainage and on the perimeter ramp with the drainage downpipes. It is then stored in rooftop tanks and at the lowest basement level, beneath the place called Eco-cell. Eco-cell is located on the ground level at the building's north-east corner, at the beginning of the ramp. It allows for penetration of natural light and ventilation air as well as for the plants extension into the car-park area below. A total storage capacity of Solaris rainwater tanks is over 700 m^3, which almost entirely covers the demand for watering plants. An integrated fertigation system provides plants with essential organic nutrients.

The project of Solaris building is adapted to local context on many levels. Similarly to CSET the design concept is based on analysis of the environmental factors, such as sun-path, sun angle, temperature and humidity. Moreover, the project’s bioclimatic strategy seriously takes into account the individual character of the ecosystem, including the need to restore and enrich its biodiversity. Consequently, the idea of bioclimatic architecture is created in equilibrium with the natural environment.

Two edifices described above: CSET and Solaris, are pioneering on a global scale. Promotion of such an approach is extremely important, as it helps to establish a model for developing countries. However, it is worth to notice that on a local scale it is possible to create bioclimatic architecture also with much lower budget. Solutions based on contemporary knowledge and technology, well inscribed into the local conditions and determinants, can be implemented at minimal cost. An impressive example was set by MCA who designed the school in Khan Younis, in the Gaza Strip.

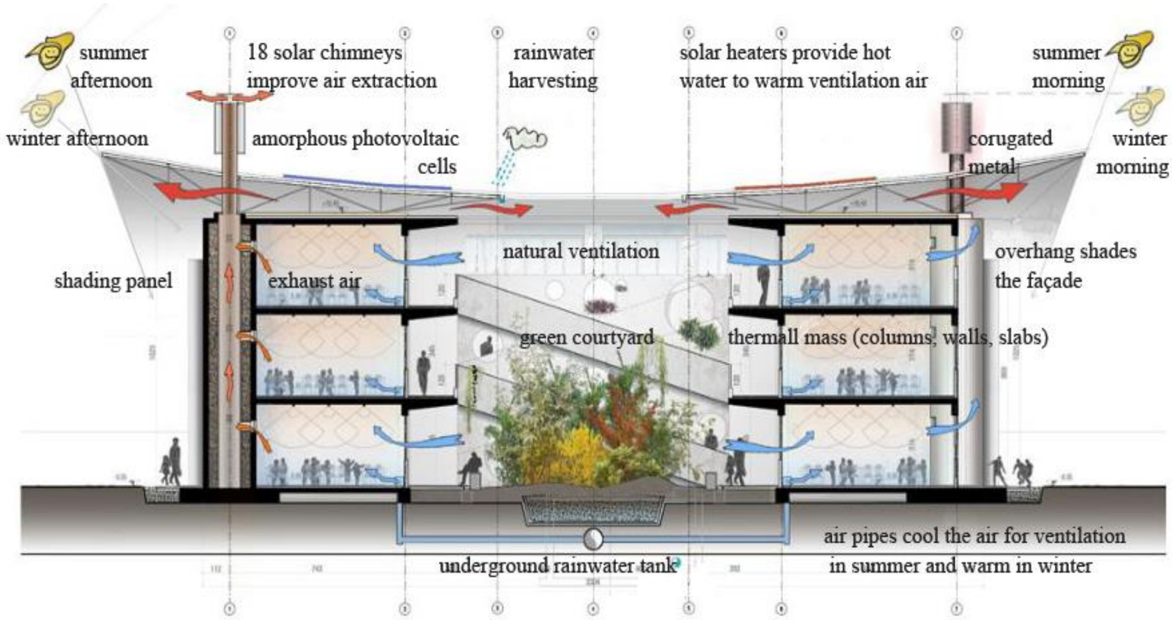

Figure 5 Kuwait School in Khan Younis (Gaza Strip, from 2014) by MCA. © MCA.

KUWAIT SCHOOL IN KHAN YOUNIS, GAZA STRIP, BY MCA.

The project of Kuwait School in Khan Younis (Gaza Strip, from 2014) was developed by MCA in partnership with UNRWA (The United Nations Relief and Work for Palestine Refugees in the Near East), with the financial support of the Kuwait Fund for Arab Economic Development. The aim of the concept was to create a green school that will provide high user comfort for 1500 children and will be totally safe for the natural environment. As the project is dedicated to the challenged area of Gaza Strip, where an access to most of resources is very limited, all the materials have to be affordable and locally sourced. The lack of fresh water is a very serious problem in Gaza Strip. Electricity is produced from generators that cause environmental pollution. To deal with this facts Cucinella proposed the pilot project to promote green approach, which may be "part of the solution to the demographic boom in Gaza where people are struggling to build homes and schools with the resources they have" (Aburawa, 2012). Therefore an off-grid building, possible to build only with locally available and renewable resources was designed. All the construction systems are as simple as possible, avoiding excessive use of advanced and expensive technologies. The only exception concerns the implementation of photovoltaic cells, solar panels and thermal technologies that improve the quality of life without harming the environment.

The Kuwait School was designed as bioclimatic building, well adapted to the local climate and environment, with an intention to enhance the biodiversity of the ecosystem. The whole construction was created in such a way that its elements support bioclimatic strategies. The concrete foundation slab provides thermal mass. Low-cost pillars designed to increase inertia, are made of concrete-earth blocks pre-casted on site, with a diameter of 2,2 m and the inner cavity filled with ground from the excavation. Vaulted slabs are made of compressed earth block. Thus formed flat arches represent traditional and very simple building technique which does not require any formwork. Overhanging roof is made of inexpensive steel beams and reflective corrugated metal sheets. The overhang allows for natural ventilation and shades the earth-brick walls. Thermal control in the building is achieved with the earthen walls and floors providing thermal mass and protecting the interiors against direct solar gain during hot days as well as against cold winds. Further elements that prevent overheating are the façade shading panels and the overhanging roof. Air pipes, located beneath the foundation slabs, cool the ventilation air in summer and heat it in winter. 18 solar chimneys fasten the exhaust air extraction from the building. Finally, the inner courtyard was designed to create pleasant green area, support natural ventilation and reduce heat island effect.

Electricity, necessary to power electrical devices, will be provided by l272 m^2 of amorphous photovoltaic cells located on the roof. Hot water for the heating coil will be delivered from 100 m^2 of the vacuum solar heaters. The classrooms will be naturally illuminated with daylight. Such designed building will have zero CO_2 emissions, will use zero oil and its heating demands will be 7 $kWht/m^2$ per year with 0 $kWht/m^2$ per year for cooling purposes.

The rainwater harvested from the roof will be used for the hygienic purposes. It will be stored in an underground tank. The recycled waste water will be used for flushing toilets (grey water) and for the plant irrigation (black water). This strategy will result in reducing water demand by 60 %. Each year water savings will bring 4600 m^3/y from waste water and 486 m^3/y from rain water.

In the project there are numerous references to the local tradition that makes it more accessible to residents and allows to express respect for their cultural heritage.

CONCLUSION

In the three case studies presented above traditional solutions developed in vernacular architecture were used as the inceptive idea as well as the source of inspiration for contemporary bioclimatic buildings. Basic methods of passive cooling and natural ventilation, commonly used in hot climate areas, were hybridized to achieve the optimal performance. In purpose to obtain the high level of indoor microclimate comfort, corresponding to modern user expectancies, advanced technology was applied. In first two edifices their budget allowed for some exemplary technological solutions, especially regarding climate responsive façade design as well as air preparation and distribution throughout the building. In CSET the non-conventional air-conditioning systems were supported with cutting-edge technologies for the exploitation of renewable energy sources. In Solaris the issue of restored, enriched biodiversity and the equilibrium of natural and built environment was of the utmost importance. The project of Kuwait School proved that the contemporary knowledge and technology, well inscribed into the local conditions and determinants, can be implemented at minimal cost. While photovoltaic cells, solar panels and thermal technologies were used to improve the quality of life, the whole architectural conception is based on passive strategies, simple construction methods and locally available, renewable resources.

The study presents the concept of bioclimatic architecture through the proper balance between traditional ideas and modern technologies. This notion allows for practical and creative usage of contemporary knowledge transfer. Nowadays original methods, dedicated to various climatic determinants, developed and verified in different parts of the world, can be supported and improved by the application of cutting-edge technologies. Although in-depth analysis of local biological and climatic conditions should always be a starting point, the worldwide information exchange can result in entirely new hybrid systems designed for the specific location needs. It is worth to note that such an approach may be used also in the areas where the lack of indigenous examples hinders the selection of the most appropriate bioclimatic solution solely on the basis of vernacular buildings studies. Therefore the contemporary bioclimatic architecture can be defined as one that combines traditional knowledge about ways of adapting dwellings to the climate with advanced research, design and technological methods in purpose to create the built environment maximally integrated with the natural environment and especially with the ecosystem in which it is placed.

It should be emphasized that buildings that are well adapted to bioclimatic conditions do not exceed the budget for comparable facilities while their environmental impact is minimal. Growing respect for ecosystems results with architectural projects that enhance biodiversity for the benefit of natural and cultural environment. Thus understood bioclimatic architecture creates great opportunities and should be perceived as the solution for developing countries (as well as for the whole world).

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Real-Time Monitoring of Envelope Assemblies

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ABSTRACT

This paper will explore how we can move from whole building energy usage data to that which can now include component level energy data (i.e., envelope assemblies). This paper will discuss a recent installation in a new campus building of a distributed low cost data acquisition system that can monitor at the component level. Five different wall/roof orientations were selected to have thermocouple sensors placed through the building envelope assembly. All these sensors will be connected to a programmable logic controller which will be integrated with a campus wide website. This system will not only become the new campus standard but will also have an enormous educational benefit to students who use this website.

INTRODUCTION

In 2010 it was estimated the value of all U.S. commercial real estate was $11.5 trillion,[1] yet the industry knows very little as to how well their buildings are performing from an energy standpoint. ASU has taken a leadership role in understanding whole building energy usage in its campus buildings by developing a campus-wide Energy Information System (EIS) and placing portions of that data on an open website called Campus Metabolism.[2] This work has received considerable acknowledgement from both the energy management as well as from the academic communities. The next step in providing leadership in this area is to provide the industry a component level energy monitoring system to understand how individual building assemblies operate in real-time.

PROJECT BACKGROUND

The origins of this project started with Campus Metabolism which is an ASU public website that displays real-time energy information for select buildings on ASU's Tempe campus. Campus Metabolism offers a unique inside view into the university's commitment to sustainability initiatives, including its focus on the value of energy efficiency and using alternative energy resources.Campus Metabolism was first commissioned in 2004, in partnership with Ameresco (formerly known in Arizona as Arizona Public Service Energy Services), after the university installed utility-grade instrumentation to accurately monitor energy usage of its buildings on campus. This data was first used by ASU's Energy Information System (EIS) from which it can be passed to other applications.

Building on the performance data being generated by the Energy Information System, Campus Metabolism extends this capability by bringing a wealth of valuable energy information and presenting it graphically for use by students, researchers and the general public. Campus Metabolism is very user-driven by allowing the user to select and graphically present energy performance data in a number of innovative ways. This site allows the user to view either the heating, cooling, electricity or the total energy consumption of the building on a daily, weekly, monthly or yearly basis. These displays also present energy data from the previous time period (day, week, month or year), thus allowing for easy historical comparisons. Figure 1 illustrates a typical screen from the Campus Metabolism website – showing kWh electricity usage in yellow and the previous days kWh electricity usage in grey.

Campus Metabolism has proven to be a very exciting tool with a high level of usage; unfortunately data that is generated is at a macro level. The macro level of monitoring a building's energy use has come a long way in the last few years; however, it

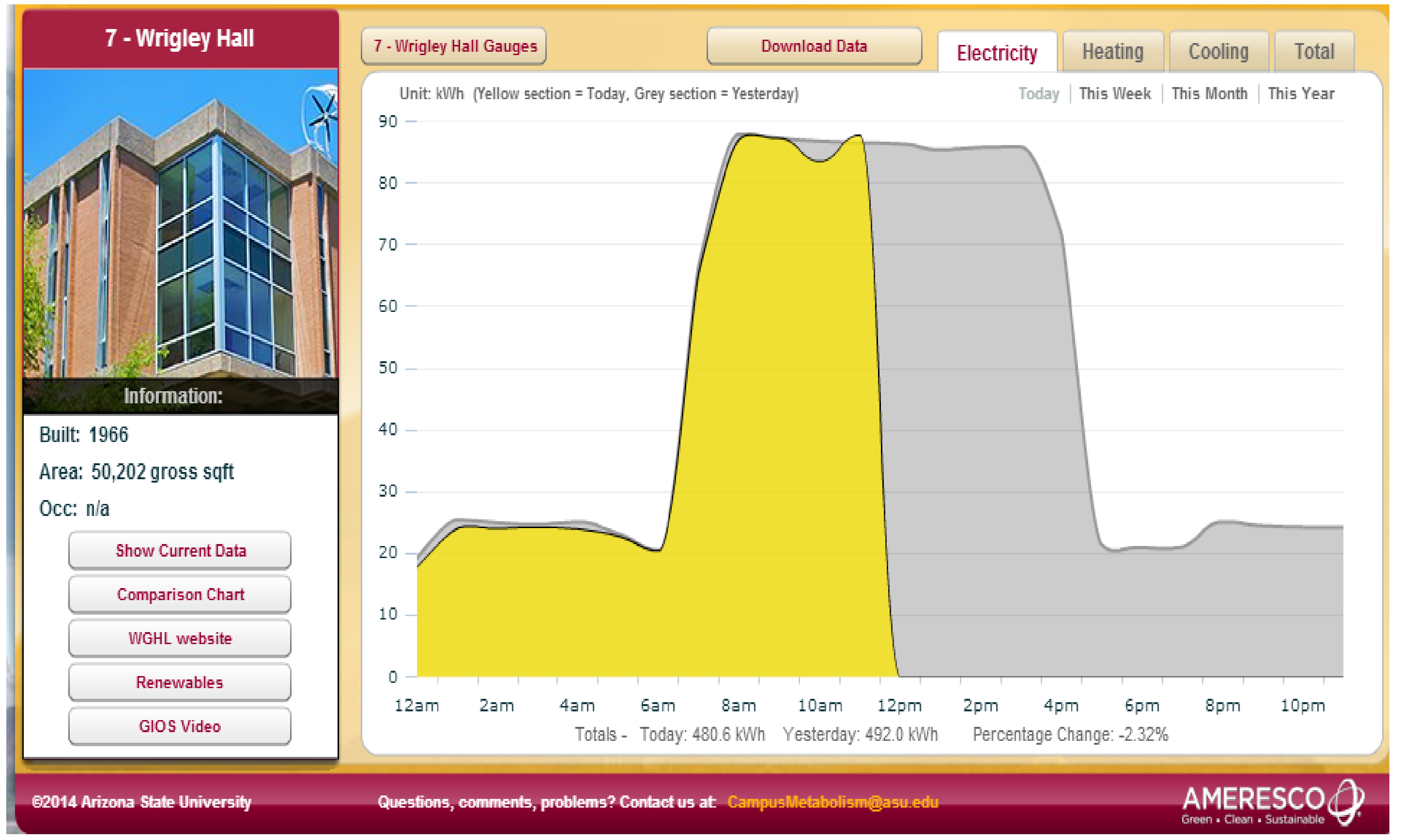

Figure 1 Typical Campus Metabolism Screen Image – Showing Daily Electricity Usage for Wrigley Hall.

is often not disaggregated enough to generate data that will identify how areas that might have small energy loss that can add up to have major energy impacts. We believe we now have the potential to install in a new campus building a low cost distributed acquisition system that can monitor down to the micro (component) level. We hope that this system will become the new standard for ASU and allow ASU to once again provide much needed leadership in the area (like it did with the release of Campus Metabolism).

Having the ability to have this type of instantaneous real-time monitoring of a building's components, such as walls and roof will have many benefits. For example, procedures for determining the thermal resistance (R-value) of building assemblies have for the most part been a theoretical exercise. R-value testing is usually done in laboratories where the testing is not started until the material reaches "steady state." Steady state occurs when a material is exposed to a heat source and is allowed to become thermally saturated so that for every single unit of heat entering on one side of the material a single unit of heat exits the opposite side. While very scientific and logical it misses an important issue relevant to predicting in-situ performance – which is the amount of time it takes to reach a steady state. Heat-balance modeling can takes this dynamic into consideration; however, for in-situ conditions it has been very difficult to determine given changing temperature and varying solar heat gain during a typical day. Thus, being able to have the ability to take a "snapshot" at any given time of day and then capture the solar gain, ambient temperature, and all surface temperatures at each layer of wall or roof construction we are confident that a more accurate R-value can be determined for each layer of wall or roof assemblies. Such information will also provide an enormous benefit to researchers, building design professionals as well as students and any parties who are interested in understanding how individual building assemblies perform in real-time.

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PROJECT DESIGN

Five different wall/roof orientations within ASU's new College Avenue Commons (CAC) were selected for monitoring. The CAC is a 137,000 square foot, five-story building for ASU's new School of Sustainable Engineering and the Built Environment. Each orientation would have the exterior wall/roof monitored by sensors placed in a linear fashion through the envelope assembly, starting on the outside. At each subsequent material layer there will be a thermocouple measuring temperature. The final interior sensors will be heat flux sensors located on the inside surface. All of these sensors will be connected to a standard programmable logic controller (PLC) which will be integrated with other campus wide monitoring systems, as well as connected to the Internet. From there users can access this data via their personal electronic devices (tablet, smart phones or computers).

In addition, to understand the external microclimatic variations, a local weather station will be installed on the roof of the CAC. This station will not only measure the standard weather parameters (like dry bulb, wet bulb, wind speed and direction) but will also include four pyranometers (solar radiation sensors) that will be oriented to measure the exact amount of radiation that each of the building's four orientations are receiving. This is vital data for determining the correct amount of solar radiation and its direct impact on performance of each of the envelope assemblies' orientations.

Figure 2 illustrates a wall section and mock-up of how the thermocouples were placed in a typical wall. The first sensor was placed on the outside of the metal cladding, the second in the air cavity of the metal cladding, the third on the outside surface of the insulation board, the forth between the insulation board and the closed cell spray-in insulation, the fifth on the inner surface of the closed cell spray-in insulation, the sixth on the cavity side of the gypsum board and the final sensor (which is a heat flux sensor) was placed on the room side of the gypsum board. The blue strip shown on the wall section drawing between the closed cell spray-in insulation and the gypsum board is the location of the humidity sensor.

The installation of the envelope sensors took place over several months. This was because we decided to wait for each trade to be finished with their work. Thus, we incrementally added sensors as each material layer of wall or roof was completed. While this added time it allowed for more accurate placement of sensors at the boundary of each material layer versus drilling holes after the wall or roof assemblies were completed. Informing each trade about the nature of this project was important so that sensors and wires would not get disturbed or inadvertently cut. As a whole, the CAC contractors as well as each trade were very supportive and interested in its potential outcome of this project.

The classroom spaces that are directly adjacent to each of the envelope monitors will have a large LCD display that will allow students in those spaces to monitor real-time envelope performance. One of these spaces is designated to be ASU's new HVAC Laboratory, which will be a teaching/research laboratory fitted with dual operating HVAC systems (a Variable Air Volume system and a Chilled Beam with a Dedicated Outdoor Air System) that can be switched between their operations. Here we would expect the classroom instructors to develop a host of learning exercises that would utilize the envelope performance data being generated to explore and test innovative HVAC operations. Thus, with the coupling of envelope monitoring with the HVAC Laboratory, a host of very innovative whole system research questions can also be asked and answered. While not the subject of this paper, we expect that a series of future technical papers will emerge from having such an innovative HVAC Laboratory operating in one of our campus buildings.

RESULTS

As of the time this paper was written, the CAC building is occupied, unfortunately the envelope sensors and data recording capability are only now being commissioned. Thus, rather than showing full operation of the five wall/roof sensor arrays we will show the three proposed Campus Metabolism screen templates that will house the sensor data and allow for display. We will also show measured data from the first wall sensor array that has been commissioned. We expect that at the time of the actual PLEA 2014 Conference (December 2014) to be able to show the real-time functional screen images of the envelope sensor pereformance from the new Campus Metabolism website.

Figure 3 illustrates the Campus Metabolism screen that would appear after a user selects the College Avenue Commons building. This screen has a brief description of the building along with four areas (Chilled Beam, Lighting, Wall Sensors and Roof) for which real-time data is available. By selecting one of these areas, a more detailed screen will appear. In our case we will select Wall Sensors which will open Figure 4. This screen shows an image of the CAC building on the left with the wall

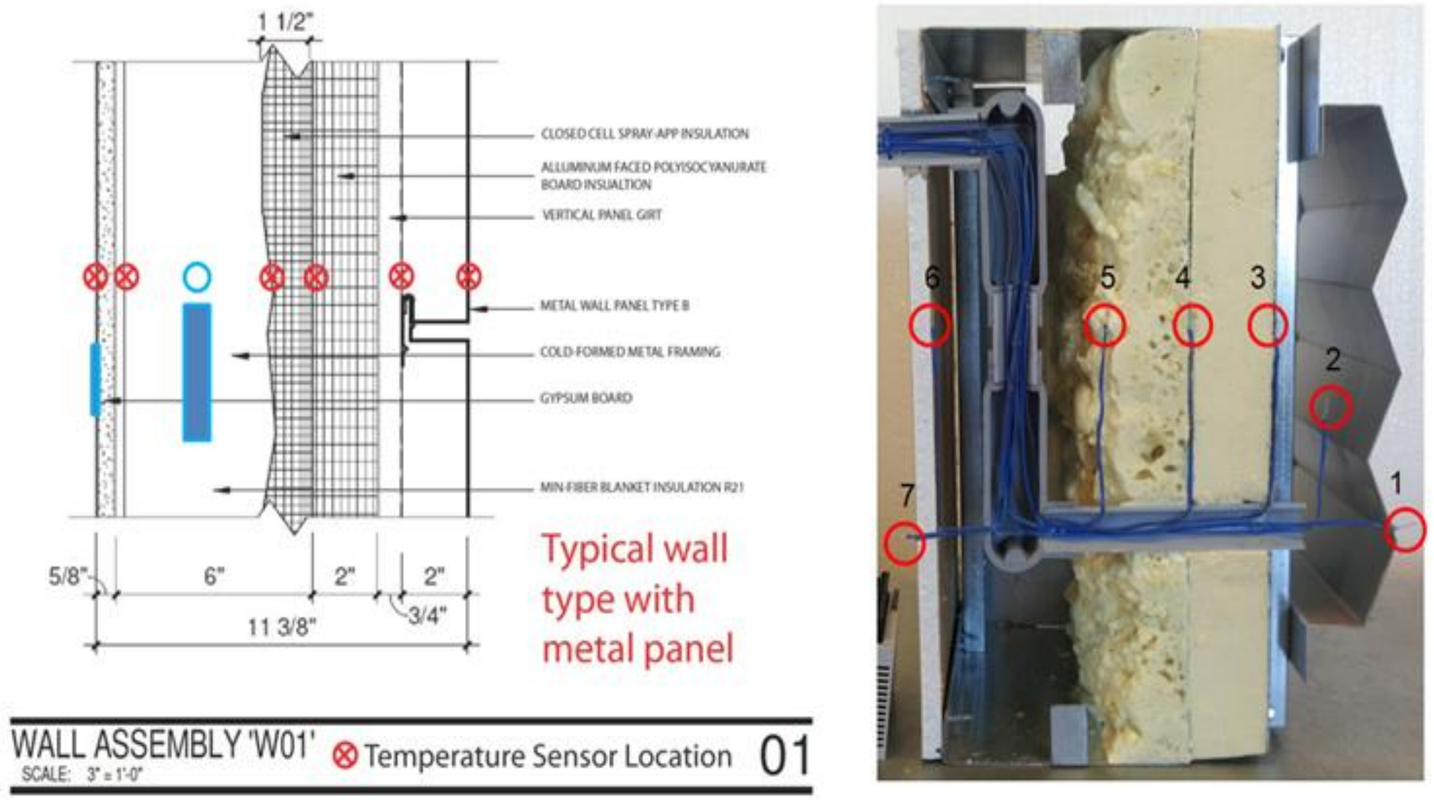

Figure 2 Typical Wall Section and Mock-Up of Thermocouple Placement (Circled in Red)

sensor placement highlighted with red dots, and the three rooms located adjacent to the sensor placement appear on the right side. By selecting the "View Snapshot" button, Figure 5 will open. In this screen we will select Room 425, which again shows an image of the CAC building on the left and below is a description of Room 425. Also on the left below the room description is a floor plan highlighting Room 425 in red and the sensor placement with a red dot. On the right side of this screen is a temperature profile through the wall section showing the temperature at each material layer. Below the temperature profile are four options (Last Hour, Last 24 Hours, Yesterday and Custom) which illustrate temperature profiles for those conditions. The Last 24 Hour option is an animation of hourly temperature changes over a 24 hour period. The Custom option allows the user to set-up a temperature profile for any time frame they would like. Finally "Current Conditions" are recorded below the temperature profile, which include data generated from the building's weather station.

Figure 6 is plot of a 24-hour temperature profile for each of the eight sensors that were embedded in the south wall of Room 425. This data was gathered on June 30, 2014, while the overall data acquisition system was being commissioned. Thus, it is very preliminary data and we are a little hesitant to interpret too much from this data. We would much rather wait until all the wall, roof and weather station data has been synchronized and operating in real-time. For example, it is not obvious why the outer sensors (in and around the metal cladding) are so spiky at the mid-day hours without the ability to review the pyranometer data for that same time period. We hope to be able to present much more in the way of interpreted findings at the time of the actual PLEA 2014 Conference. In the completed Campus Metabolism website, Figure 6 would become the 24-hour snapshot screen on the right side of Figure 4.

CONCLUSION

This project has taken what is usually done in a laboratory and turned the building into the laboratory that can monitor in real-time to show and graphically represent the actual thermal performance of each layer of a typical envelope assembly. This exercise outlines an effective approach for determining real-time temperature performance of envelope assemblies. It is of growing importance to understand how buildings perform down to the component level. Information like this will lead to better

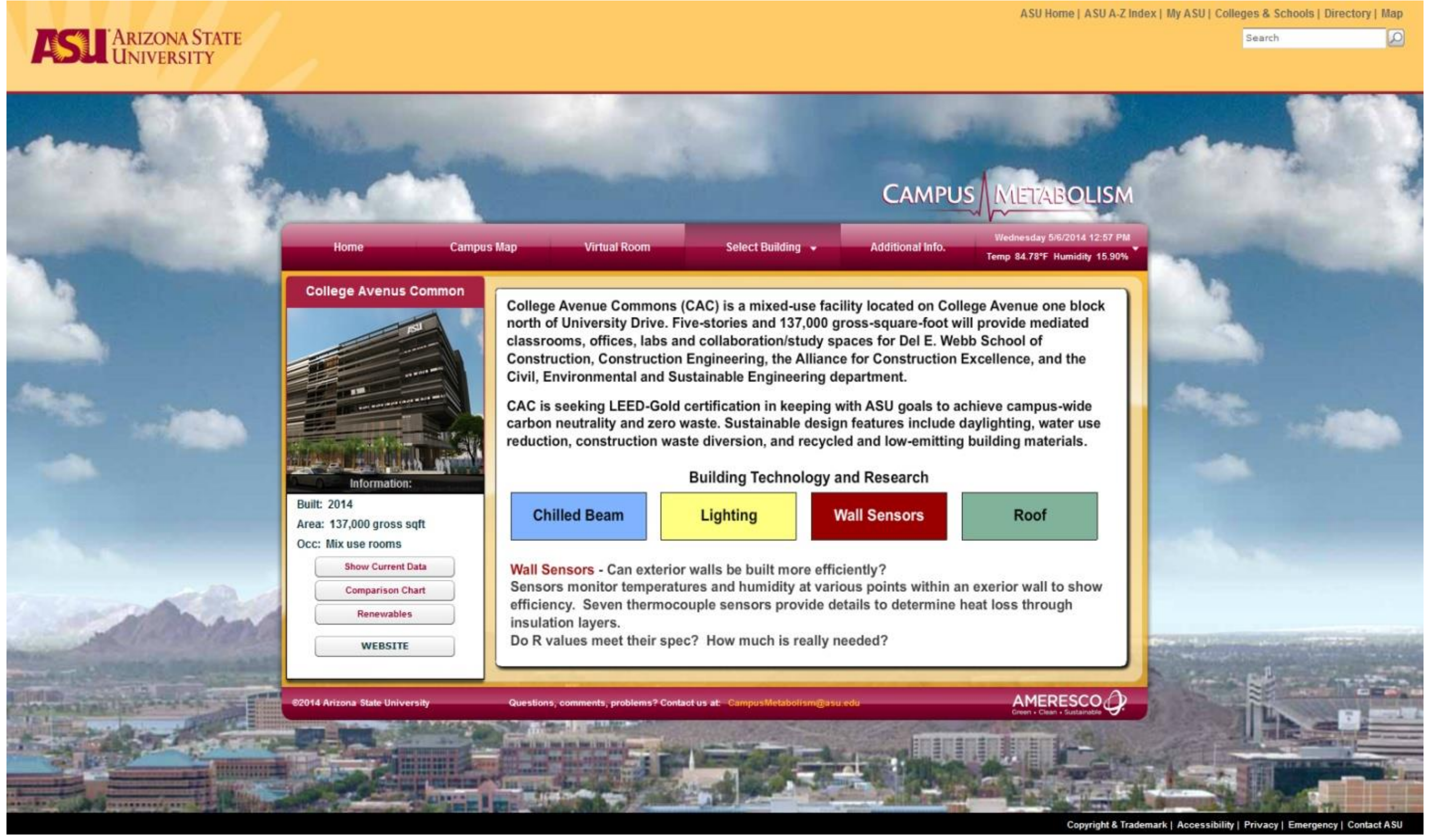

Figure 3 Screen describing the CAC and showing the four areas for which real-time data is available.

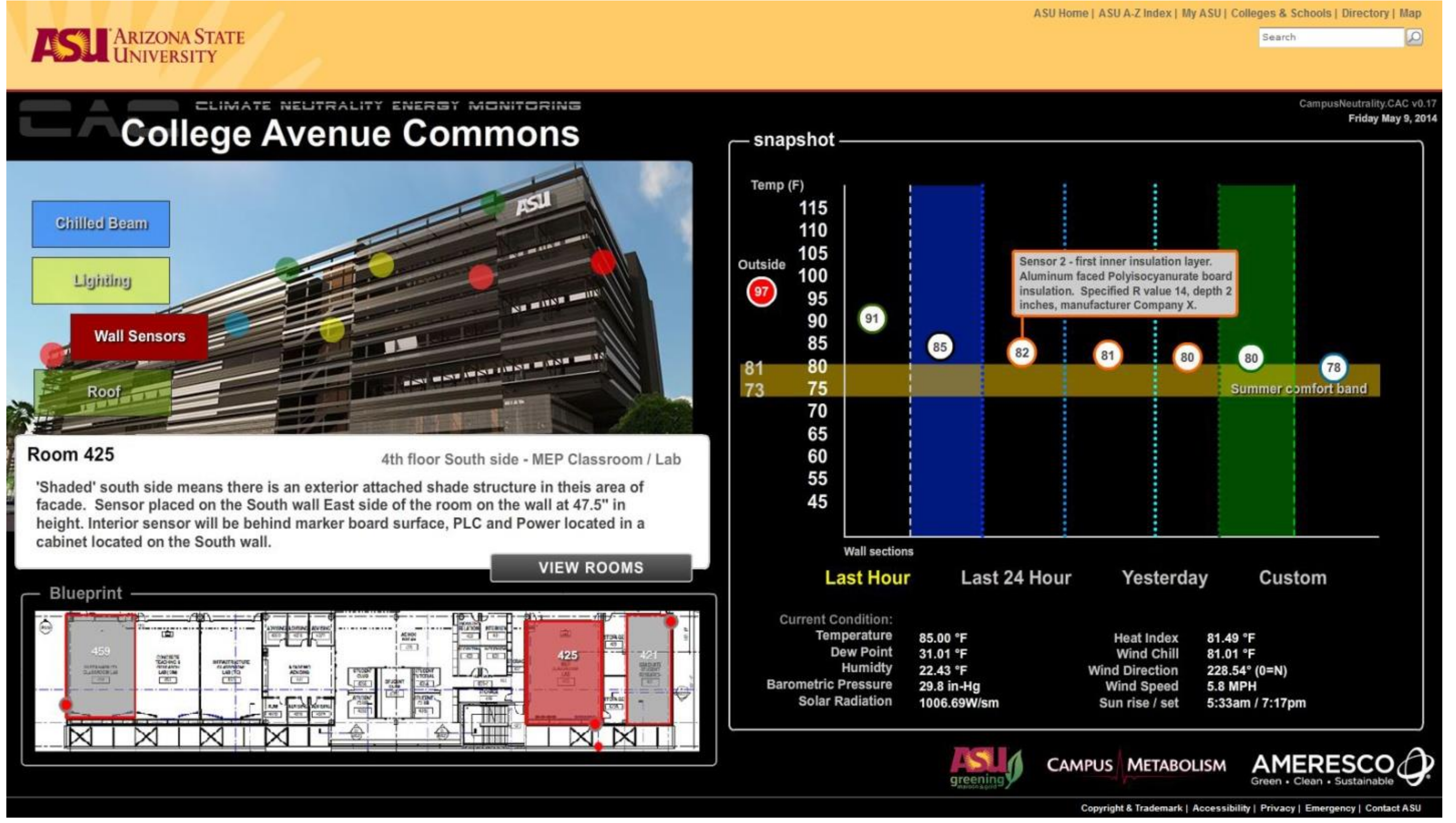

Figure 5 Screen showing Room 425 (highlighted in plan in red) and wall temperature profile

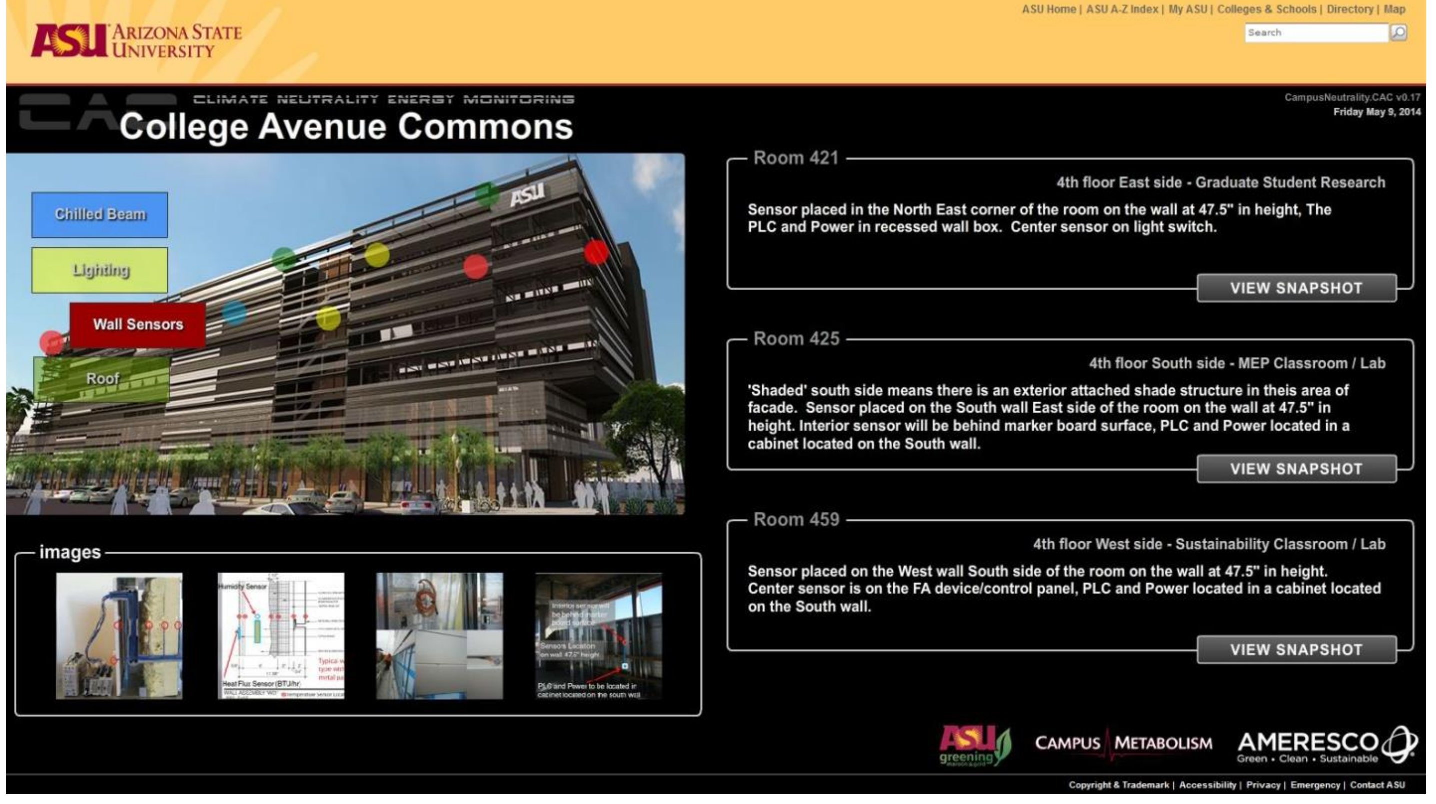

Figure 4 Screen showing the three rooms adjacent to wall sensors and sensor placement (with red dots)

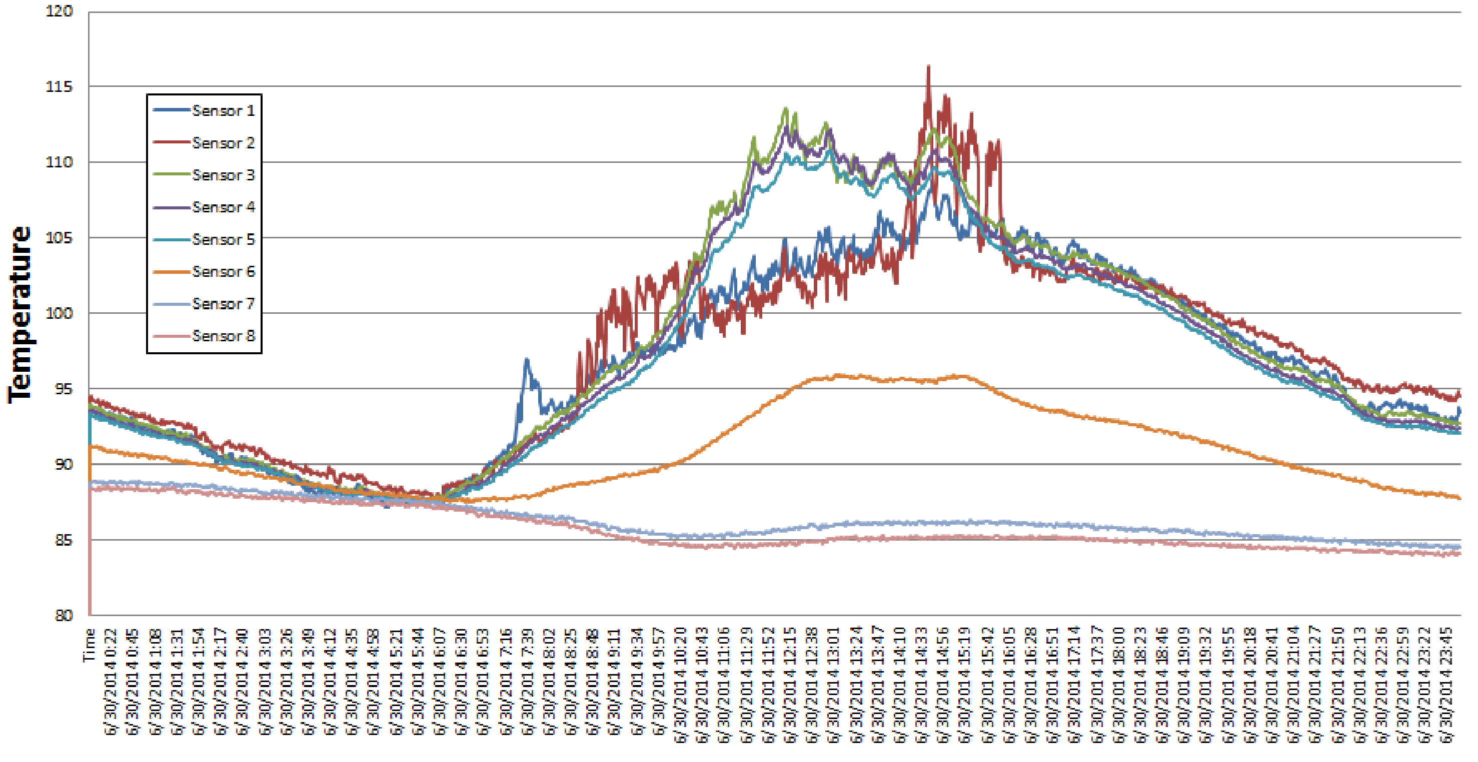

Figure 6 24-hour temperature profile of the eight sensors in the south wall of Room 425 understanding of how building envelopes perform and operate as well as striving for a high level of data transparency. It is hoped that projects like this will give others the information needed to undertake similar installations. By utilizing the Web and presenting data in an interesting and graphically clear manner, it is hoped that it will lead to a host of new and exciting educational outcomes.

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Session 7C : User behavior, thermal comfort & energy performance

PLEA2014: Day 3, Thursday, December 18
10:25 - 12:05, Grace - Knowledge Consortium of Gujarat

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Occupant Feedback in Energy-Conscious and 'Business as Usual' Buildings in India

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ABSTRACT

Buildings account for 30% of energy consumption in India, and it is estimated that 70% of the projected commercial building stock by 2030 is yet to be built. The recently established five-year US-India Centre for Building Energy Research and Development (CBERD) project aims to address the barriers for adopting low energy consuming strategies in buildings in India, while exploring the lessons that can also be applied to the US context. This paper evaluates the performance of two energy-conscious (EC) and two 'business as usual' (BAU) buildings in Ahmedabad, India using a combination of physical measurements, and a web-based occupant survey. The survey includes questions about Indoor Environmental Quality (IEQ): thermal comfort, indoor air quality, air movement and acoustics; it also asked questions about adaptive controls such as windows and fans.

The EC buildings performed well in many categories compared to the 'business as usual buildings'. One of the EC designed buildings in particular performed exceptionally well compared to the CBE database which consists of over 600 buildings mainly from the US but also from 9 other countries. In the other three buildings, dissatisfaction prevailed mainly with acoustic quality and office layout due to lack of speech privacy and visual privacy, but this is common across the larger database. More than 70% occupants were satisfied with thermal comfort in all except one of the BAU building and of the occupants who were uncomfortable mostly cited air movement being too low as the reason for discomfort.

INTRODUCTION

Building construction is rapidly growing in India, primarily in the commercial sector with office type work. The construction boom, along with the hot climate and increase in purchasing power in metropolitan cities such as Mumbai and Chennai, has led to an unprecedented growth in air conditioner unit sales at almost 20% per year (McNeil and Letschert 2008; Sivak 2009). Studies are being done with Governmental support to evaluate energy efficient ways of providing comfort (Manu et.al. 2012). The Center for Building Energy Research and Development (CBERD) project is a joint initiative of the US Department of Energy and Indo-US Science and Technology Forum that aims to address the barriers for adopting low energy consuming strategies in buildings in India, while exploring the lessons that can also be applied to the US context. In order for low-energy space conditioning strategies to be widely adopted, it is crucial that occupant comfort and well-being are simultaneously maintained or enhanced, and occupant feedback is an invaluable source of information for investigating these impacts. Of particular interest is the use of windows and fans, since air movement is a very cost efficient way of providing comfort.

Occupant feedback is also helpful in diagnosing prevailing issues in a building. For instance, it has been found that in air-conditioned buildings, a large number of occupants are dissatisfied with the temperature in their workspace during summer because it is too cold (Abbaszadeh et.al. 2006; de Dear et.al. 1991). Appropriate action can be taken to address this issue by identifying if there are specific zones in the building that have cold dissatisfaction complaints due to over-cooling. The energy savings accrued by changing the air-conditioning unit setpoint even by few degrees could be significant, especially in warm climates (Hoyt et.al. 2009).

In this paper, we present the results from a post occupancy evaluation of two energy conscious (EC) and two 'business as usual' (BAU) offices using the Center for the Built Environment (CBE) online survey tool and physical indoor temperature measurements. We evaluate the satisfaction in each category and benchmark the performance to the CBE database of 600 buildings. This study is intended to be a pilot for a larger study which will be scaled up to cover buildings with different passive systems in different climates of India.

METHODOLOGY

Building selection

India has a varied range of office building types, starting from those that are purely naturally ventilated to those that are highly energy intensive and use air conditioning throughout the year. This range includes mixed mode buildings that use air conditioning during extreme condtions and operate in natural ventilation mode for the rest of the year. Buildings that may be air conditioned for all twelve months but have efficient system and operation or employ unconventional air conditioning systems also fall in this varied mix of office building typologies. The buildings for this study were selected for the purpose of covering this range as best as possible.

In India, a 'business as usual' office building is likely to have several climate-responsive strategies such as external shading to reduce solar heat gain, interior blinds for controlling glare and visual comfort, operable windows for natural ventilation, and some attention to daylighting. All four of the buildings studied here have these features.

That said, not all Indian buildings have been designed to optimize the performance of these passive features, or to make a conscious attempt with the active mechanical systems to reduce energy consumption. The two buildings in our study that did at least one of these things are being characterized as energy-conscious (EC) design. The other two buildings are being characterized as 'business as usual' BAU, noting again that a BAU building in India will already have more climate-responsive features than its counterpart in the U.S. The wall construction is similar in all four buildings, made predominantly of brick masonry with cement plaster on both sides.

EC-1 is the office of an architecture firm. It takes the approach of relying on passive features to maintain thermal comfort inside and is most likely the least energy intensive out of the four buildings. It was designed to primarily operate in fully naturally ventilated mode, but was later retrofitted with air conditioners following the installation of computers. The building has a high vaulted roof structure over the studios that facilities better ventilation. It has large openings on the north set higher in the building, while the lower openings on south are smaller to reduce direct radiation from entering the space. In the low ceiling areas, clerestory windows provide diffuse daylight across the day. In other places, glass brick is sometimes used to provide diffused daylight. Both the operable windows and pedestal fans are operated by the occupants. The building mass is compact, and the building is partially underground, further reducing the impact of direct radiation. Glazing is approximately 25% of the wall area. The vaulted roofs have an air cavity filled with ceramic fuses (9" long conical pieces mixed with concrete) to provide thermal insulation, and the entire roof is covered with high SRI tile. The immediate surrounding is heavily landscaped with dense trees and water bodies, generating its own microclimate. The building has window air conditioners and operates as a switch-over type mixed mode building where occupants turn off the air conditioner and open the windows when the outdoor conditions are suitable for natural ventilation. The total floor area is spread across four levels, including the mezzanine level. The lower and first floor is occupied by the permanent staff while the mezzanine floor is occupied by temporary staff such as interns and international scholars. 48 of the 54 permanent staff participated in survey, all of them located on lower floor.

EC-2 is a building design and consulting firm. It is a LEED Platinum building, but took an entirely different approach than EC-1 in their energy-conscious design. The firm we studied occupies the seventh floor of a 11-story building that has the usual business-as-usual features described previously. Other than installing double-glazed windows, EC-2 did not attempt to optimize the envelope, but instead reduced their energy consumption by addressing the active systems that serves their air conditioned office space. They have a very efficient HVAC system, demand controlled ventilation, energy-efficient lighting and lighting controls, and occupancy sensors. Like all the buildings in our study, EC-2 has operable windows, but they are not often used by the occupants as the air conditioning is used across the year. There are no interior fans. The wall construction is much more heavily glazed than EC-1 (51-75% of the wall area). In spite of the high WWR and lighting controls, the building seems to rely more on artificial lighting than natural daylighting. The materials used in EC-2 conform to LEED 2.1 specifications such as low VOC paints, coatings, adhesive, sealants and fabrics, green label carpets and cleaning materials. 31 out of the 91 occupants answered the survey.

Both of the following BAU buildings are similar in that they have not made any conscious attempt in either the envelope, active system, or control strategies to reduce energy consumption. However, even without explicit lighting controls, they both rely mostly on natural lighting for the majority of the occupied hours. Both buildings also have ceiling fans (which are not being provided most of the time in newer, sealed buildings in India).

BAU-1 is an office of a computer software developer firm in a heavily urbanized area, located on eighth floor of an 11-story building (similar to EC-2 being on an intermediary floor of a taller building). It is representative of the most energy intensive building with a business-as-usual envelope and air conditioning system and operation. The office has a variable air volume (VAV) type central air conditioning unit that is on throughout the year. The walls are heavily glazed, with the WWR being almost identical to that in EC-2 (51-75% of the wall area). The windows are operable and have a reflecting glass. As in the other buildings, BAU-1 has interior blinds and exterior shading. 27 out of the 140 occupants answered the survey.

BAU-2 is an office of a building construction and MEP consulting firm in a less dense and more vegetated area, located on ground and first floor of an 8-story building. It has a variable refrigerant flow (VRF) type central air conditioning unit, operable windows and ceiling fans. The glazing area is in between the other examples (30-50% of the wall area). The windows have a clear glass, compared to the reflective glazing of BAU-1. While the air-conditioning in BAU-1 operates almost continuously throughout the year, in BAU-2 occupants have a choice to operate it when indoor becomes uncomfortable. 40 out of the 46 occupants answered the survey.

CBE web-based survey tool

The CBE web-based survey tool is an efficient way of remotely getting occupant feedback on indoor environmental quality (IEQ) and various other aspects of the building. Participation in the survey is voluntary and occupants can choose not to answer any question. The questions in the survey were designed after extensive inputs from facility managers and designers so as to report the most useful feedback (Eisenhower 2000). The survey consists of a core module with eight IEQ categories and additional modules such as window and fan usage. Since the surveys were being admisistered in India, the phrasing of the questions and options were tailored to suit the local culture and parlance. The survey asked occupants to rate their satisfaction during summer with these different aspects on a 7-point scale that ranged from -3 (Very dissatisfied) to 0 (Neutral) to +3 (Very satisfied). The tool also has a unique feature that is helpful for diagnostic purposes; when an occupant votes to be dissatisfied in any category, the tool automatically follows up with branching questions that ask about the reasons for dissatisfaction. Details about the building features such as floor area, number of occupants, LEED compliance and type of HVAC system, envelope and glazing are filled out by the building manager separately. More details about the CBE survey tool can be found in (Zagreus 2004). A list of the most relevant survey questions is illustrated in Table 1.

Table 1. Important Categories Included in the CBE survey

Variable	Questions asked
Thermal comfort	Satisfaction with temperature, ability to control temperature, thermal comfort during summer
Indoor air quality	Satisfaction with air quality (i.e. stuffy/stale, cleanliness, odors)
Air movement	Satisfaction with amount of air movement, ability to control amount of air movement
Window usage	Satisfaction with operable windows (summer and winter and monsoon) Importance of having an operable window to the user Times adjusted (daily, weekly, monthly) Time of adjustment Reasons to ‘open’ or ‘close’ a window
Fan usage	Satisfaction with ceiling fans, Times adjusted during summer(daily, weekly, monthly), Time of adjustment, Reasons to turn ‘on’ or ‘off ’ a fan
Acoustics	Satisfaction with noise level and sound privacy

RESULTS

Weather

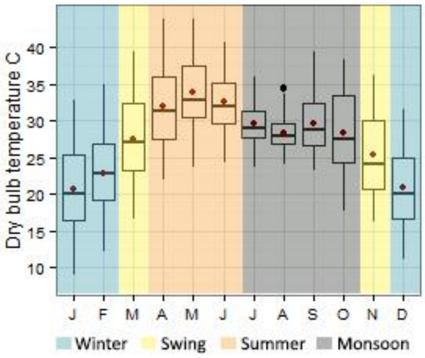

Figure 1. Ahmedabad weather

Figure 1 shows the boxplot of outdoor dry bulb temperature (DBT) based on the ISHRAE weather file (EnergyPlus webpage). Ahmedabad experiences a semi arid climate with predominantly three seasons: summer, monsoon and winter. April to June is the summer season where the mean DBT is above 30 ˚C with a highest recorded value of 44 ˚C. Summers are dry with a mean relative humidity (RH) of 53%. July to October is the monsoon season where the mean monthly DBT is 28 ˚C and mean RH is 70%. November and March are the two transition months with mean DBT of 26 ˚C and mean RH of 47%. December, January and February are the winter months where the mean DBT is comparatively lower at 21 ˚C and mean RH is 52%.

Summary of occupant feedback in all the four buildings

Figure 2 shows the percentile scores compared to the overall CBE dataset, and Figure 3 shows the mean percentage satisfied per survey category in each building (Occupants voting +1 and above were counted as satisfied). In both, green colors designate better performance and orange designates low performance. Figure 2 illustrates that EC-1 (which uses more passive strategies to achieve its energy efficiency) is the best performer of the four buildings, and compared to the CBE database ranked fairly well in most of the survey categories except for ‘office layout’ and ‘air movement’ satisfaction. EC-2 (using improved active systems to achieve low energy consumption) did relatively well in thermal comfort, acoustics, and lighting performance, but ranked low in office layout, air quality and workspace satisfaction. Of the BAU buildings, BAU-1 is the lowest performer of the four buildings across most of the categories, while BAU-2 ranked relatively well in thermal comfort and lighting, but low in air movement satisfaction.

For illustrative purposes in Figure 3, a satisfaction percentage below 70% is assumed to be the threshold for concern. This is more flexible that the conventional 80% satisfaction threshold used in thermal comfort standards, for example. Figure 3 shows that 70% or more occupants were satisfied in EC-1 in all survey categories except for office layout and air movement. It’s interesting to note that even though acoustic satisfaction was in the 95th percentile in Figure 2, this is based on only 78% of the occupants being satisfied, as shown in Figure 3. That is because acoustics generally receives the lowest satisfaction scores in the database, so even 78% is considered quite good, and was also unusually high compared to the other four buildings. The reasons for that are not entirely clear, although the high valuted roof could possibly be a factor. The dissatisfaction with office layout was related mainly with visual privacy (too many people walking around in the work area) and the amount of workspace available for work (this may be due to this being a traditional architecture firm that requires a lot of workspace for paper drawings). The dissatisfaction with air movement prevailed mainly because of the lack of sufficient air movement (rather than air movement being too high), and the inability to control it. However, these complaints were limited to only two zones, D and E. This was surprising since these zones have pedestal or bracket fans, both of which should be adequate to increase air movement close to the person, even more effectively than stratification created by the vaulted roof. This may suggest that even though these fans are available, there are reasons that people are not using them or they are not located properly.

In EC-2, although the building was in the 90^{th} percentile of the CBE database for thermal comfort, this is associated with only 71% of the occupants being satisfactied. This is because this is a pervasive problem in buildings, and thermal issues are usually the #2 complaint (following acoustics). Of the IEQ categories, occupants were most satisfied with lighting, but the highest satisfaction ratings had nothing to do with IEQ (i.e., office furnishings, general building satisfaction, and cleanliness/maintenance). The satisfaction percentage in EC-2 was lowest with acoustics, air quality, office layout and air movement. Lack of sound privacy was the main reason for acoustic dissatisfaction while it was the lack of visual privacy for the dissatisfaction with office layout. A few occupants from EC-2 opined that the air was stuffy/stale, not clean and had a bad odor; the source for bad odor was mainly from the toilets. However, the complaints were limited to one particular zone. With regards to air movement satisfaction, occupants were mainly dissatisfied with amount of air movement (saying they preferred to have more air movement) and the ability to control the amount of air movement. This is not surprising given that this building does not have fans.

BAU-1 is having the biggest challenges with their workplace conditions; less than 70% of the occupants were satisfied in all the categories except for workspace satisfaction, where it was 77% (Figure 3). Higher satisfaction may, in part, be due to this office having relatively low occupant density (10 sq.m. per person, compared to a more typical 6.5 sq.m. per person for India). Amongst the dissatisfied categories, acoustic quality, office layout and thermal comfort were the categories in the lowest satisfaction range; around 50% or less. Similar to EC-2, lack of sound and visual privacy were the main reasons for dissatisfaction with acoustics and office layout respectively. Overall thermal comfort satisfaction was very low in BAU-1 compared to the other three buildings. Those who were dissatisfied cited multiple reasons of discomfort such as incoming sun, air movement being too low and the heating/cooling system not responding quickly to the thermostat.

Occupant response in BAU-2 was in sharp contrast to BAU-1; 70% or more occupants were satisfied with all categories except acoustics (Figure 3). Sound privacy was once again the main source of dissatisfaction. An important point to note with regards to acoustics dissatisfaction in EC-2, BAU-1 and BAU-2 is that occupants were less dissatisfied with noise levels as compared to sound privacy (both of these questions make up the combined metric for acoustic quality); this pattern is common across the CBE database.

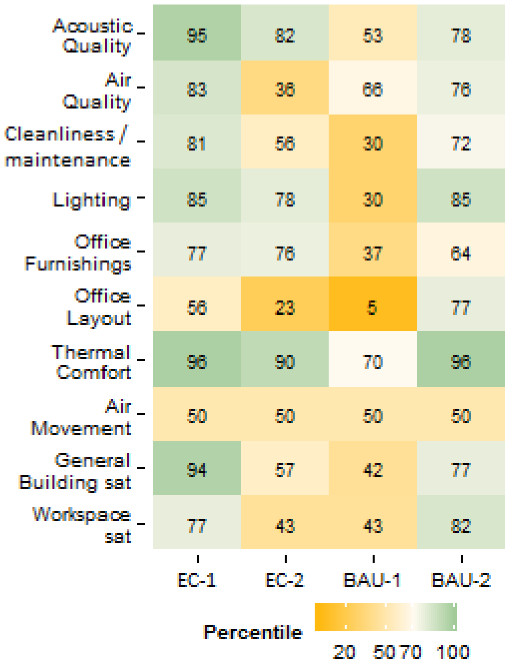

Figure 2. Percentile ranking of the case study buildings compared to the CBE database.

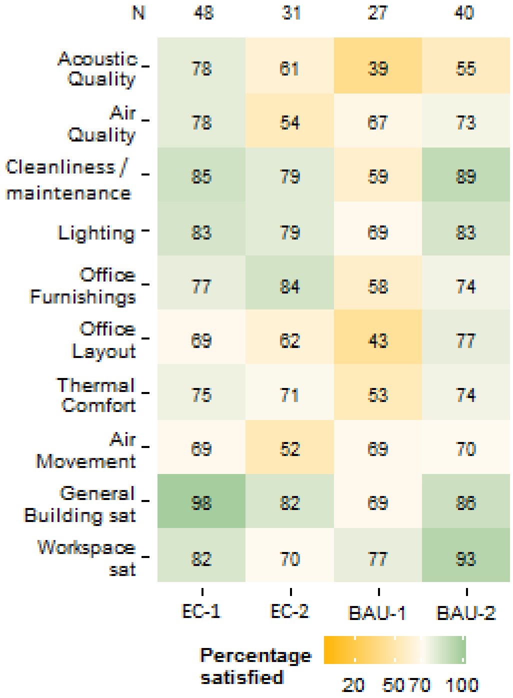

Figure 3. Percentage of occupants satisfied in each case study building

Thermal comfort during summer

Ahmedabad experiences hot summers. Occupants were asked about their thermal comfort opinion 'in general' and specifically during summer. However, to understand thermal comfort during the extreme climate, evaluating thermal comfort satisfaction in summer is more crucial than in general. Using the 7-point satisfaction scale described earlier, Figure 4 (a) – (e) shows the mean thermal comfort response in each zone (labeled alphabetically) of EC-1, EC-2, BAU-1 and BAU-2 respectively (note that BAU-2 has two floors). The color corresponds to the mean value and the numeric is the number of votes in each zone. Figure 5 (a) – (e) shows the distribution of indoor temperature during occupied hours monitored from February – April 2014 in each building. The color and numeric both represent the mean value of indoor temperature while the green dot represents the sensor location.

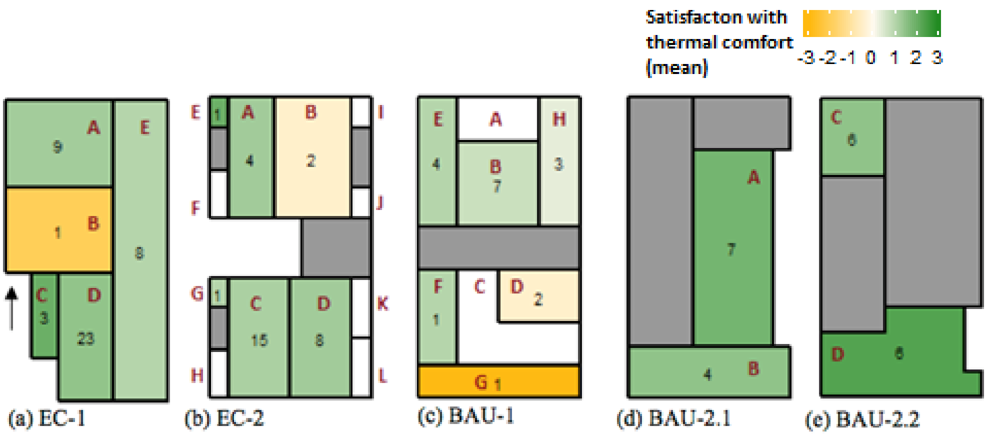

Figure 4. Satisfaction with thermal comfort during summer.
The scale ranged from -3 (Very dissatisfied) to 0 (Neutral) to +3 (Very satisfied)

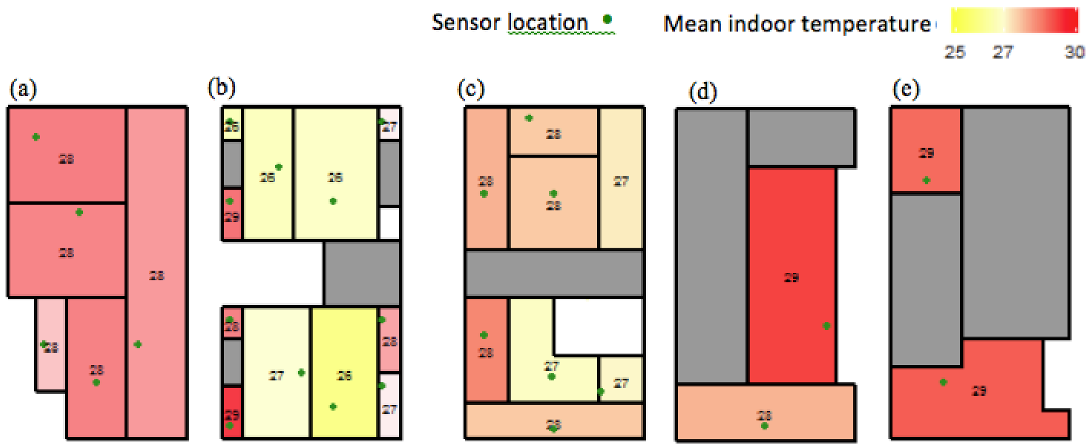

Figure 5. Indoor temperature (°C) between February to April.

More than 70% of the occupants were satisfied with thermal comfort during summer in 3 of the buildings - EC-1 (N=46), EC-2 (N=31) and BAU-2 (N=37) - while only 50% were satisfied in BAU-1. The most cited reason for thermal discomfort in all the four buildings was air movement being too low. The mapping in Figure 4 helps in identifying the zones where the mean satisfaction vote is less than zero. For example, lowest satisfaction occurred in zone B in EC-1, zone B in EC-2 and zone D and G in BAU-1. However, these zones had two or less number of responses and thus these findings are only illustrative, and nothing conclusive can be said.

The mean value of indoor temperature during occupied hours monitored from Februry – March was between 26 – 29 ˚C. The distribution was mostly uniform across all the zones in the building except for EC-2 where the core zones were cooler than the perimeter zones. This could be very likely because EC-2 had the widest floor plate compared to the other three buildings.

In all four of the buildings, occupants voted that room air conditioners and window blinds/shades were the controls that thay were most frequently adjusted. During summer, the majority of the occupants said they either drank something cool or covered the window to keep themselves comfortable.

Window and fan usage

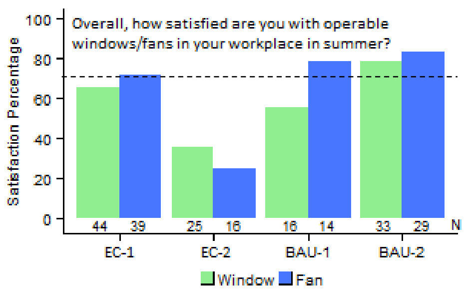

Figure 6. Satisfaction with windows and fans.

Windows and fans are two cost efficient ways of providing comfort in warm climates, and are common in buildings in India. Occupant satisfaction feedback regarding both these adaptive actions is of interest mainly during the summer. Figure 6 shows the percentage satisfied with operable windows and ceiling fans in all four buildings during summer. Looking first at windows, overall, greater than 70% satisfaction with operable windows was only achived in BAU-2. A few occupants from EC-1 said the windows were inaccessible and there were things blocking the window. This was surprising since EC-1 is the building that paid particular attention to using passive, architectural strategies to achieve low energy use. In EC-2, the LEED Platinum building where the focus was more on efficienct active systems, occupants said most of the windows were fixed and in BAU-1 some of the reasons which made it difficult to use windows were the inability to open windows fully and complaints from co-workers. The most frequently cited reasons for opening a window in all the four buildings were, ‘to feel cooler’, ‘to increase air movement’ and ‘to let in fresh air’. Interestingly, the prevailing reasons to close a window were ‘to feel cooler’, ‘outdoor temperature getting warmer than indoors’ (both of these related to having air-conditioning on during a hot day), and ‘to reduce outdoor noise.’ These reasons show that window interaction is driven predominantely by outdoor temperature, air quality and noise levels.

Looking now at fan usage, overall, more than 70% were satisfied with fans during summer in three of the buildings - EC-1, BAU-1 and BAU-2 (the satisfaction with fans was low in EC-2 because the building did not have any). The most cited reasons to turn on a fan in EC-1, BAU-1 and BAU-2 were 'to feel cooler' and to 'increase air movement' while the reason to turn off a fan was to 'reduce air movement' and because 'a co-worker requested it.' These are all as one might expect, and the majority of the occupants in EC-1, BAU-1 and BAU-2 said they were very sure of having the desired effect when they interacted with fans.

DISCUSSION

The occupant feedback surveys revealed that one of the energy conscious buildings (EC-1) was performing well (i.e., it had a satisfaction percentage of above 70% in 8 out of ten categories.) Overall, in all of the buildings occupants were primarily dissatisfied with the acoustics and office layout, which is common across the entire CBE database. Acoustic dissatisfaction is an important area that needs to be carefully evaluated since it is often seen as a potential barrier for natural ventilation. One of the arguments against having natural ventilation in a city like Ahmedabad is that operable windows would bring in outdoor noise. However, the survey results show that occupants were more dissatisfied with sound privacy than noise levels, which has more to do with the open plan layout. In terms of the sources of noise that bothered workers, people talking on phone and overhearing private conversations were the most frequently cited sources of acoustic dissatisfaction, rather than outdoor noise.

Another result worth noting is that all the buildings ranked low in the air movement satisfaction category compared to the CBE database, and the lack of air movement was repeatedly cited as the reason for thermal discomfort. Occupants were also dissatisfied with the ability to control air movement and opined that they needed more of it. This dissatisfaction prevailed mainly in zones that did not have fans, which means more attention needs to be given to providing sources of air movement in these buildings. Amongst those who had fans, the main reasons to turn on a fan were to feel cooler and increase air movement. Moreover, when asked about the confidence of having the desired effect on turning on a fan, the majority of the occupants voted that they were confident about this effect. This shows that occupants perceive fans as fast-acting and they rely on it for achieving comfort in a short span of time. Windows on the other hand were opened to let in fresh air in addition to feel cooler and increase air movement. There was a consistent opinion about the reasons to close a window, i.e. when the outdoor got warmer than the indoors. The key take-away from this result is that the occupants prefered to have air movement and when there was a combination of windows and fans in use, they worked well in providing it.

The results also revealed an interesting aspect of occupant satisfaction in EC and BAU buildings. Given that BAU-2 performed better than EC-2, this indicates that one cannot necessarily conclude that a building designed for better energy efficiency will result in better occupant satisfaction as well. In addition to needing to pay more attention to air movement and other indoor environmental factors, there could possibly be latent factors such as interior layout, work culture, and connection to the outdoor views that are important (all of these were better in BAU-2).

This study is a pilot for further research where surveys will be conducted across buildings in different climates of India. Although spatial mapping of thermal comfort and temperature is a powerful method of diagnostics, we were not yet able to generalize about the impact of relevant building design issues due to the uneven distribution of the number of responses (i.e., zones where occupants voted to be dissatisfied with thermal comfort had very few votes.) The scaled up study will consider ways by which we will ensure a minimum number of responses from each zone.

CONCLUSIONS

Indoor Environmental Quality (IEQ) parameters were evaluated in two energy-conscious (EC) and two 'business-as-usual' (BAU) buildings in Ahmedabad. The EC building that utilized more passive architectural approaches performed well in most of the categories compared to the buildings in the CBE database, the other three buildings had multiple categories of concern. Overall, the occupants expressed maximum dissatisfaction with sound and visual privacy. They were mostly satisfied with thermal comfort except in one BAU building. Those who were dissatisfied most frequently cited 'air movement being too low' as the reason for dissatisfaction. In buildings that had fans, it was perceived to be a fast acting way of providing comfort. Fans were operated mostly due to thermal and air movement needs while windows were operated due to indoor air quality and acoustic reasons in addition to the two former reasons.

ACKNOWLEDGEMENTS

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Assessment of Air Velocity Preferences and Satisfaction for Naturally Ventilated Office Buildings in India

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ABSTRACT

Free-running buildings (i.e. naturally ventilated buildings with no mechanical systems for heating or cooling) have the potential to be much more energy efficient than air-conditioned buildings. This paper is based on approximately 3200 instantaneous thermal comfort and 1500 long term background survey datasets from a large scale field study conducted in free-running Indian office buildings. Responses to air movement satisfaction and air movement preference questions, together with concurrent measurements of indoor environmental parameters of air and globe temperature, relative humidity and air velocity are used for this study. The paper gives an insight into the operation of ceiling fans and windows, and the range of air velocity experienced by office workers in free-running office buildings. It gives the relationship between measured indoor air velocity, concurrent air and globe temperature and relative humidity. Instantaneous responses are correlated with the on-site observations on window and ceiling fan operation, as well as indoor environmental measurements. The assessment of preferred air velocity from ceiling fans and operable windows as an adaptive measure in this paper contributes to the development of better designed free-running office buildings in India.

INTRODUCTION

India is a rapidly growing economy with a population of more than 1.2 billion which marks 17.6% increase in 10 years. According to the Indian Census of 2011, the country has about 46 cities with population of over 1 million (Census Organization of India) and many more cities will join this list in a matter of a few years. People need buildings to live and work. The growth in population, therefore, is linked to the rapid increase in building construction and infrastructure demand. Building construction and operation requires energy, for most part, in the form of electricity. Coal, a non-renewable resource, is the primary source of electricity in the country. To sustain the GDP growth at 7-8% (projected average), energy security must be ensured. On the other hand, global climate change and the environmental degradation points to the need to chart a more responsible growth path. It is clear that in the current scenario of climate change, energy efficiency in buildings is the most important 'energy source' for India.

The primary end use of electricity in buildings is to provide thermal comfort to occupants through air conditioning. It is therefore important to focus on what constitutes thermal comfort for people in buildings. ASHRAE defines it as 'a state of mind that expresses satisfaction with existing environment'. It also precribes standard thermal comfort conditions for air conditioned and free-running buildings (ASHRAE, 2010). In India, the National Building Code (Bureau of Indian Standards, 2005) provides construction guidelines, administrative regulations, development control rules and general building

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requirements related to fire safety, materials, structural design, plumbing and building services. The Energy Conservation Building Code of India (Ministry of Power, 2007) prescribes minimum standards for energy efficiency in buildings, soon to be mandated across the country. None of these codes propose an explicit thermal comfort model for India. Some individual researchers have worked in this area but their work is limited to residential studies in selected regions of the country (Singh, Mahapatra, & Atreya, 2011; Indraganti, 2010). The dearth of extensive field studies to understand thermal comfort in offices across all climate zones of India led to the conception of the India Model for Adaptive Comfort (IMAC) study in 2011 (Manu, Shukla, Rawal, de Dear, & Thomas, 2014 forthcoming). The primary objective of this study was to develop an adaptive thermal comfort model for India.

This paper presents a part of the IMAC study, focusing on the role of air velocity in the thermal comfort sensation of building users. Adjusting local air velocity through the use of ceiling fans and/or windows is one of the most significant behavioral adaptation mechanisms. Studies show that the building occupants use this mechanism in warm or warm-humid conditions to achieve comfort. Nicol (1974) reported a reduction in thermal discomfort at 32-40 ˚C at air velocity >0.25 m/s in regional studies in India and Iran, supplemented by similar findings from Sharma and Ali (1986). Field studies in the sub-tropical climate of Hong Kong indicate that air velocity of 1.0-1.5 m/s would likely satisfy 80% of the occupants thermally in summer season and that with 1.5 m/s air velocity, the upper limit of comfort temperature reached 33.5 ˚C (Cheng & Ng, 2006).

Studies have also indicated the need for increase in air velocity even in air conditioned buildings to offset increase in temperature (Arens, Turner, Zhang, & Paliaga, 2009). Feriadi (Feriadi & Wong, 2004) reports the tendency of the occupants to modify the hot and humid living environment by turning on fans and opening the windows. Field studies in the warm and humid climate of Bangladesh show an increase in comfort temperature with air velocities greater than 0.3 m/s (Mallick, 1996).

METHODOLOGY

The analysis presented in this paper is based on the data collected over four campaigns of surveys in office buildings in India, spanning a period of one year. These surveys were administered in five Indian cities selected as representative locations for the five climate zones prevalent in India – warm & humid, hot & dry, composite, moderate and cold. In order to document a wide range of indoor environmental conditions, surveys were administered in naturally ventilated, mixed-mode and air conditioned buildings in these five cities during summer, winter and monsoon seasons. The instantaneous thermal comfort surveys (TCS), which were repeated every season, gathered responses related to thermal sensation, preference and acceptability, air movement satisfaction and preference, clothing and activity. These were accompanied by simultaneous measurement of the indoor climatic parameters – air temperature, globe temperature, relative humidity and air velocity. Building Use Studies (BUS) methodology (Building Use Studies Ltd., 2014) was also used as a post-occupancy evaluation tool to gather long-term responses (Leaman, 1995). It has questions framed to draw responses to the workspace environment on a seasonal basis from past experiences of the respondents. The questionnaire covers aspects such as thermal comfort, ventilation, lighting, noise, indoor air quality, personal control. A total of 6330 TCS and 2002 BUS responses were gathered from 16 buildings under the IMAC 2014 project. Of these, 2005 TCS and 652 BUS responses are from occupants in buildings that were naturally ventilated throughout the year and constitute the data set analyzed in this paper.

In the IMAC study, buildings that did not have any mechanical cooling or air-conditioning systems installed and had ceiling fans and operable windows, were classified as pure naturally ventilated (NV) buildings. Survey responses from NV buildings have been separated from those of the mixed-mode buildings working in naturally ventilated mode at the time of the survey (NV_{mm}). Even though the indoor conditions follow the outdoor in both NV and NV_{mm}, the premise for this distinction is that subjects in NV_{mm} mode experience AC (air conditioned mode) for a part of the year and, therefore, may have different responses to, and expectations from, the thermal environment of the work space, as compared to those who never experience AC at work. This classification was done during the analysis of the study and it was found that none of the buildings in the composite climate zone could be categorized as NV.

The present paper focuses on the seven NV buildings, one each in the hot and dry zone (HD1) and warm and humid (WH1), two in moderate (MD1, 2), and three in cold (CD1-3) climate zone (Table 1).

Table 1 Survey schedule and number of responses

Building		TCS Summer responses (Month)	TCS Monsoon responses (Month)	TCS Winter responses (Month)	BUS responses (Month)
HD1	Ahmedabad	137 (May)	121 (Jul)	167 (Jan)	123 (Jul)
MD1	Bangalore	38 (May)	48 (Aug)	33 (Jan)	46 (Aug)
MD2		132 (May)	149 (Aug)	127 (Jan)	138 (Aug)
WH1	Chennai	90 (Jun)	85 (Oct)	104 (Jan)	98 (Oct)
CD1	Shimla	64 (Jun)	68 (Aug)	69 (Dec)	68 (Aug)
CD2		120 (Jun)	126 (Aug)	111 (Dec)	108 (Aug)
CD3		83 (Jun)	72 (Aug)	61 (Dec)	71 (Aug)
Total		**664**	**669**	**672**	
			2005		**652**

Note: HD = hot and dry; MD = moderate; WH = warm and humid; CD = Cold

Table 2 Study parameters and scales used

Parameter	Scale						
Thermal comfort field studies (TCS) 'Right Here, Right now'							
Thermal sensation	Hot (+3)	+2	+1	Neutral (0)	-1	-2	Cold (-3)
Thermal acceptance	Unacceptable (1)			Acceptable (2)			
Thermal preference	To be warmer (1)			No change (2)			To be cooler (3)
Air movement satisfaction	Unsatisfactory (1)	2	3	4	5	6	Satisfactory (7)
Air movement preference	More air movement (1)			No change (2)			Less air movement (3)
Fan operation	OFF (0)	ON (1)		Not available (N/A)			
Window operation	Shut (0)	Open (1)		Partially open (2)		Not available (N/A)	
Building Use Studies (BUS) long term survey							
Air stillness	Still (1)	2	3	4	5	6	Draughty (7)
Air quality	Unsatisfactory (1)	2	3	4	5	6	Satisfactory (7)

Three responses related to thermal sensation, acceptance and preference, and two responses related to air movement satisfaction and preference from TCS were used for the analysis. From BUS, responses to the fields related to air stillness and satisfaction with the overall air quality were included. Status of fans and windows for each survey response was also recorded. The scales and values for each of these variables are given in Table 2.

RESULTS

Indoor Climate

Air velocity in naturally ventilated buildings is primarily a function of cross ventilation by opening of windows or the use of ceiling fans. In the NV dataset, the mean indoor air velocity observed was around 0.2 m/s (range = 0-1.96 m/s; SD = 0.4) across all seasons and climate zones. Figure 1 plots the mean, maximum and minimum air velocities for each climate zone-season aggregate for NV buildings. Of the four climate zones, the highest mean air velocity of 0.6 m/s was observed in warm and humid zone in monsoon and summer, and maximum air velocity of 1.96 m/s in monsoon, the highest of all other zones. This can be explained by greater use of ceiling fans or windows to reduce the discomfort resulting from high humidity and temperature. Hot and dry climate zone also presented trends of high values of mean and maximum air velocity. There was almost no variation in mean air velocity in cold climate zone. This is because ceiling fans were not available in any of the buildings surveyed and are not a common feature in buildings in cold climate. Across all climate zones, the highest mean air velocity occurred in summer (0.3 m/s) and the lowest in winter (0.1 m/s).

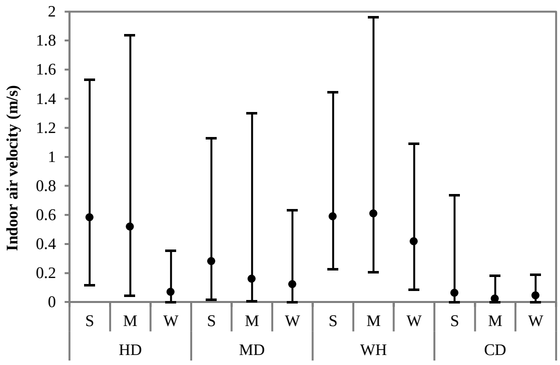

Figure 1 Prevalent air velocities in NV buildings in different seasons and climate zones (S=Summer; M=Monsoon; W=Winter)

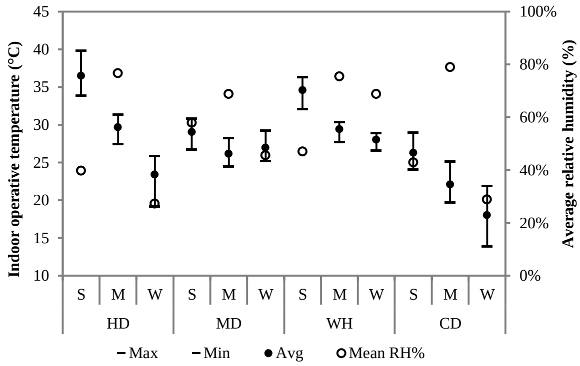

Figure 2 Prevalent indoor operative temperatures and relative humidities in NV buildings in different seasons and climate zones (S=Summer; M=Monsoon; W=Winter)

Comparing Figure 1 and Figure 2, it may be observed that the indoor operative temperature trends were followed closely by the mean air velocity trends – air velocities increased exponentially with increase in indoor operative temperature, till about 30 ˚C, beyond which there was no change. It was, however, difficult to relate mean air velocity with the variation in mean relative humidity. This may indicate that the increase in mean air velocity as an adaptive measure was, in most instances, related to adapting to high indoor temperature rather than high humidity levels.

Figure 3 plots the mean, maximum and minimum air velocities with respect to the mean indoor operative temperature. In the range of 21.5-29.5 ˚C, the relationship was best explained by expressing indoor air velocity as an exponential function of indoor operative temperature, explaining 80% of the variance in air velocity in NV buildings. Mean air velocities at indoor operative temperatures less than 21.5 ˚C were constant at 0.05 m/s and those at temperatures greater than 29.5 ˚C were constant at 0.6 m/s. This may be indicative of the limitations of changing the air velocity as an adaptive mechanism for very high or low indoor temperatures. Figure 4 examines the relationship between mean air velocity and outdoor 7-day weighted running mean air temperature. The exponential function explained 47% of the variance in air velocity with outdoor temperature. The relationship, however, was not as strong as in the case of indoor operative temperature in Figure 3.

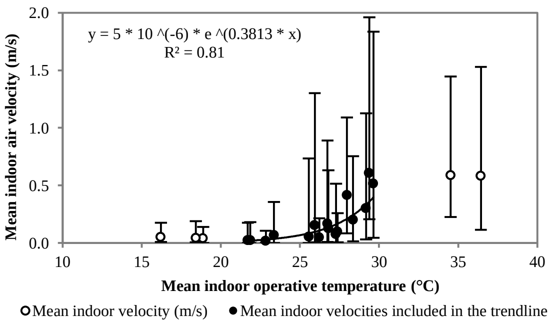

Figure 3 Variation in air velocity with indoor operative temperature

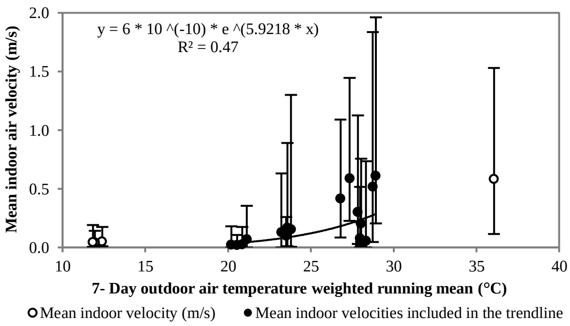

Figure 4 Variation in air velocity with outdoor air temperature

Adaptive opportunities: status of fans and windows

For almost all survey responses, fans were observed to be ON during all three seasons in the warm and humid climate (Figure 5). This may be to alleviate discomfort due to high temperatures in summer and high humidity levels in monsoon and winter. In hot and dry zone, almost all fans were reported to be ON in summer and monsoon and almost all were OFF in winter.

A more mixed use was observed in the moderate climate zone where fans were ON in 80% instances in summer and almost 25% in monsoon and winter. Cold climate zone did not have any fans available, except for a small fraction of 4-10% owing to isolated cases of table/wall mounted fans. Window use was highest in hot and dry and warm and humid climate zones in monsoon with 71-78% responses indicating open windows (Figure 7). 45-60% of the responses reported open windows in summer, across all climate zones. For monsoon and winter, however, the variation was greater.

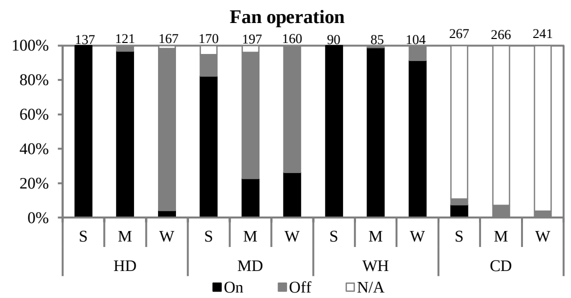

Figure 5 Status of ceiling fan operation in NV buildings in different seasons and climate zones

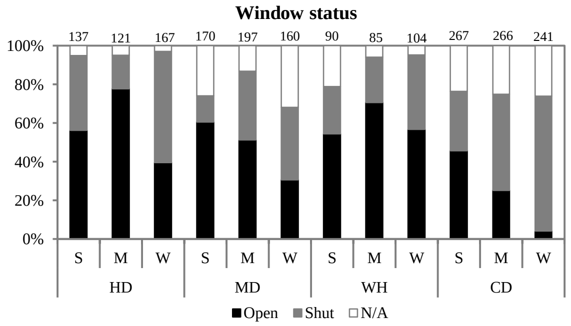

Figure 7 Status of window operation in NV buildings in different seasons and climate zones

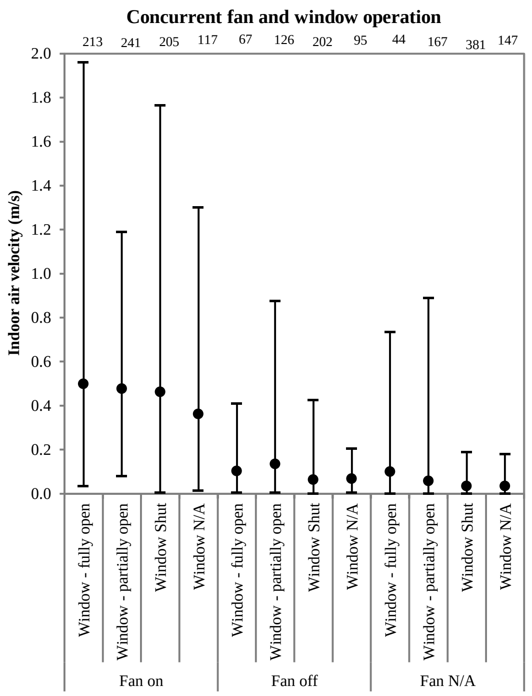

Figure 6 Status of concurrent operation of ceiling fans and windows in NV buildings in different seasons and climate zones

Figure 6 superimposes mean air velocity with fan and window operation. It clearly indicates that window use had little effect on mean indoor air velocity. When the fans were OFF or not available, opening or shutting the windows led to prevalent mean air velocities ranging from 0.06-0.13 m/s. On the other hand, when windows were shut or unavailable, operation of fans induced mean air velocities ranging from 0.36-0.46 m/s. In warm and humid zone, more than 90% fans were ON in all seasons. In hot and dry zone, almost 100% fans were ON in summer and monsoon.

In Figure 8, indoor operative temperatures were binned at 0.25 ˚C and percentage of fans and windows in operation was calculated for each temperature bin. A logit curve best explained fan operation with change in indoor operative temperature. It indicates that percentage of fans in ON mode increased exponentially with increase in indoor operative temperatures. When indoor operative temperatures were higher than 31 ˚C, all fans were ON and almost 90% of the fans were OFF below 25 ˚C. Figure 8 also shows window operation was used as an adaptive measure till the indoor operative temperatures reached 32 ˚C at which point all windows were open. Beyond 34 ˚C, occupants seemed to be shutting the windows, again as an adaptive measure to avoid excessive heat ingress from outdoors into their workspaces. A polynomial trend line (R^2=0.66) was used to capture occupant behavior more closely with actual operation. The polynomial curve, however, was still not able to explain the instances where all windows were open. A linear trend line (R^2=0.79) was then used which was able to explain window operation till 32 ˚C of indoor operative temperatures. Within this limit it indicated a significant relationship showing that with every 1 ˚C increase in indoor operative temperature, the proportion of open windows increased by 5%.

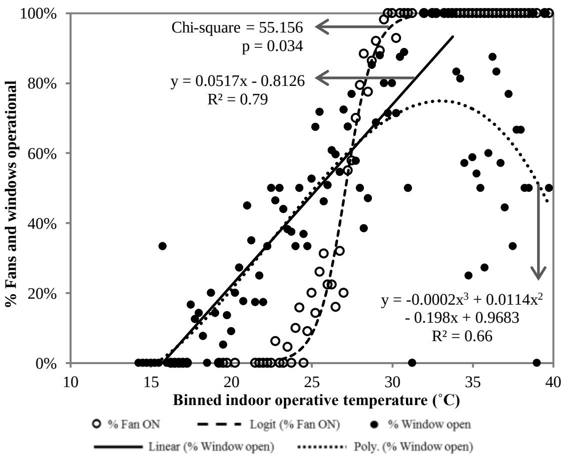

Figure 8 Proportion on fans and windows in use in NV buildings expressed as a function of indoor operative temperature

The figure establishes the use of fans and windows to alleviate discomfort owing to high indoor temperatures. It also indicates the level of indoor thermal conditions at which these adaptive measures were used. This provides a critical piece of information regarding occupant behavior that is important for building energy simulation but has not been available for workspaces in India.

Impact of air movement on thermal comfort

It is evident from Figure 9 that 65% of the people who voted neutral for thermal sensation also voted for no change in air movement. Almost 70% of people who voted ‘hot’ (+3) on the sensation scale preferred more air movement. Percentage of responses voting for no change in air movement decreased towards both ends of the sensation scale (hot and cold). The preference for more air movement, however, increased as the sensation votes moved towards +3. 57% of the people feeling ‘slightly cool’ preferred no change but a staggering 40% wanted more air movement. In Figure 10, almost 70% of the respondents voting for no change in the thermal environment did not want any change in the air movement. 65% of the people who wanted to be cooler also preferred to have more air movement. This agrees with the general idea that in an uncomfortably warm environment, people tend to want high air velocity as an adaptive measure. It is interesting to note, however, that more than 40% of people who were feeling cooler than normal (wanted warmer) also wanted more air movement even though more air movement would make them cooler than they felt. Almost 60% of the people who found their thermal environment unacceptable voted for more air movement (Figure 11). About the same ratio wanted no change in air movement among those who voted the thermal conditions as acceptable. Almost 43% of the respondents in NV buildings wanted more air movement and 3% wanted less air movement.

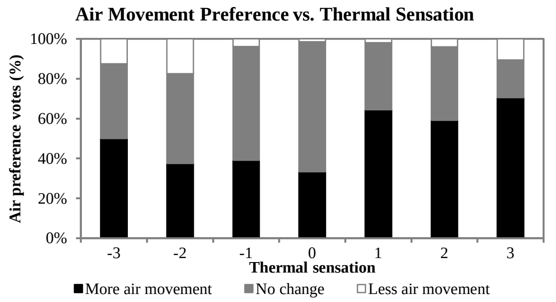

Figure 9 Distribution of air movement preference votes on the thermal sensation scale

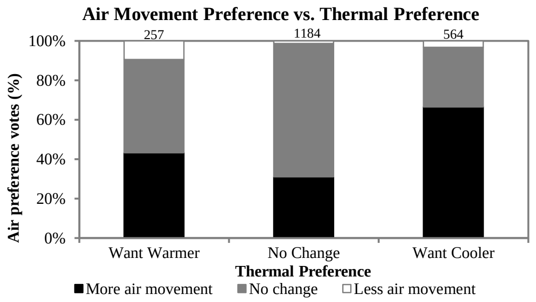

Figure 10 Distribution of air movement preference votes across thermal preference response categories

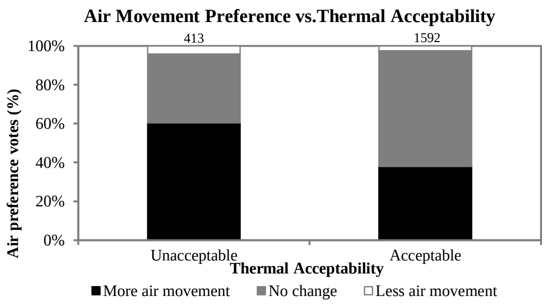

Figure 11 Distribution of air movement preference votes across thermal acceptability response categories

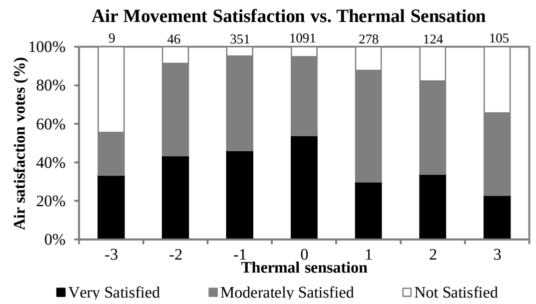

Figure 12 Distribution of air movement satisfaction votes on the thermal sensation scale

In order to assess air movement satisfaction, the 7-point scale from Table 2 was converted into a three-point scale by merging the responses in the first two categories into one ‘not satisfied’ category and merging the last two into ‘very satisfied’. The central three categories formed ‘moderately satisfied’. The number of votes (%) was then plotted against thermal sensation (Figure 12). Among the subjects who voted for neutral thermal sensation, 54% were very satisfied, 41% were moderately satisfied and 5% were dissatisfied with air movement. The percentage of dissatisfied respondents increases as the sensation moves towards ±3 vote. Almost 35% of the respondents voting ‘hot’ are dissatisfied with the air movement. Interestingly, this percentage increases to 45% for those voting ‘cold’. 60% subjects who did not want to change their thermal environment were moderately satisfied with the air movement.

Almost 85% of the people who were very satisfied with the air movement did not want any change but 15% wanted more air movement (Figure 13). This suggests a discrepancy between air movement satisfaction and preference. Of those who were moderately satisfied with the air movement, 60% wanted more air movement. It is important to note, however, that 95% of the subjects not satisfied with air movement wanted more air movement in the work space.

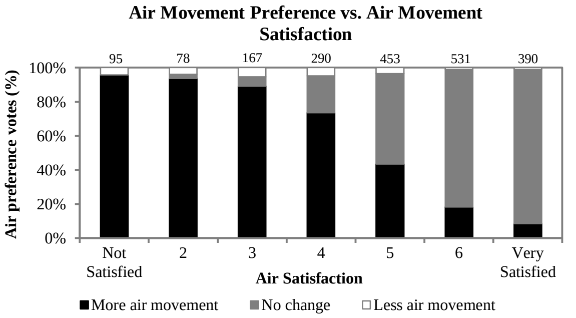

Figure 13 Distribution of air movement preference votes on the air movement satisfaction scale

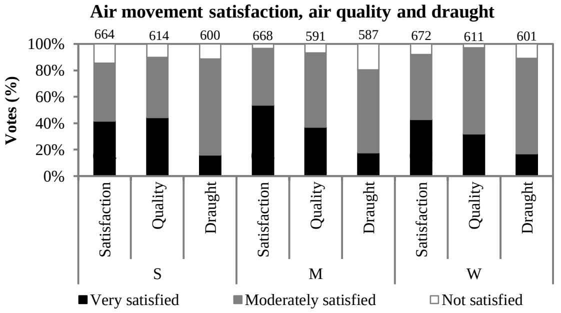

Figure 14 Comparison of air satisfaction votes from TCS with the air quality satisfaction and air draught votes from BUS

Reponses related to overall air quality and draught from the BUS questionnaire were compared with air movement satisfaction (Figure 14). It is important to note here that the BUS survey was administered in the seven NV buildings in the monsoon season. So, the responses to air quality and draught for summer and winter seasons were based on respondents' memory of their experiences related to these aspects of the work space. Draught does not seem to be a problem in the NV buildings, with only 10-20% of the subjects interviewed reporting draught across three seasons. Almost 60-70% responses indicated that the workspaces were moderately draughty. Reponses to the question of air quality satisfaction indicate 30-45% subjects being very satisfied and 45-65% being moderately satisfied. Maximum dissatisfaction responses of 10% occur in summer season.

CONCLUSION

The results from the study revealed the range of air velocities prevalent in NV office buildings in India, reaching as high as 2.0m/s. Indoor air was nearly still (average air velocity < 0.1 m/s) in cold climate zones across all seasons. Mean air velocities in all seasons in warm and humid zone were highest (0.4-0.6 m/s) as compared to other climate zones. They were closely related to the indoor operative temperatures and increased exponentially from 22-30 ˚C. Below 22 ˚C, mean air velocities were less than 0.1m/s and above 30 ˚C indoor operative temperatures, they were constant at 0.6 m/s. This indicated that high air velocity was used as an adaptive measure to address discomfort due to indoor warmth rather than humidity. There was a strong relationship between mean indoor air velocities and indoor operative temperatures. The dependence of mean air velocities on outdoor warmth, however, was not very robust.

Fans and windows are very important adaptive measures for subjects working in naturally ventilated spaces. That said, higher air speeds were primarily a contribution of fans (0.3-0.4m/s) and windows had a limited role (<0.06 m/s) to play. One may suggest that more than the need for higher air movement, windows were opened for other reasons such as cooling the indoors (when outdoor is pleasant), fresh air, daylight and view.

Window use also showed a very robust correlation with indoor operative temperature explained by a linear trend till 32˚C indoor operative temperature. Occupants started operating windows when the indoor operative temperatures reached 15 ˚C. All windows were open between 32-34 ˚C and closed again when temperatures approached 34 ˚C. The logit regression predicted that ceilings fans started operating at 23 ˚C and 100% of the fans were in use at 31˚C and higher indoor operative temperatures.

The study also shows that the office workers in India tend to prefer more air movement, or higher air velocities. Even when they found the thermal environment acceptable, almost 40% wanted more air movement. Respondents' dissatisfaction with air movement was primarily due to the lack of it. Air movement preference and satisfaction were closely related to thermal sensation. Subjects preferred more air movement as the sensation moved towards the either end (+3 and -3) of the 7-point sensation scale. At +3, 70% respondents wanted more air movement and at -3 the percentage of respondents wanting more air movement was 45%. Even when subjects were cooler than they would like, they wanted higher air movement.

Most importantly, the study provided valuable insights into occupant behavior in office buildings. Some of the results from this study could be used to better inform the simulation models that are usually very different from the real buildings. The results give very clear indications of how fans and windows are operated in naturally ventilated office buildings and could help build operation schedules for building energy simulation.

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NOMENCLATURE

TCS = Thermal Comfort instantaneous survey
BUS = Building Use Survey
HD = hot and dry climate zone
MD = moderate climate zone
WH = warm and humid climate zone
CD = cold climate zone
S = summer
M = monsoon
W = winter
NV = fully naturally ventilated buildings

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Evaluation of Comfort Concepts with Tempered Air and Elevated Air Speed in Tropical Climate

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ABSTRACT

All too often today's buildings require massive resource input. The way we define the "comfortable" thermal conditions play a significant role in this environmental impact and the systems and energy required to air condition and cool our buildings. Adaptive comfort models, developed on the basis of field studies in tropical and subtropical climates, give evidence that extended operative temperature and humidity ranges are acceptable for indoor climate especially when combined with elevated air speed controlled by the occupants. Adaptive comfort typically can be achieved with less mechanical systems. The aim of this paper is to propose a low-energy, hybrid system design method as an alternative design strategy to "static" and deterministic HVAC control systems. In this context adaptive is not about changing people's comfort expectations, it is about changing environmental conditions, especially the air speed, to create comfort and to compensate for higher temperatures and humidities.

The non-governmental organization BRAC is planning a new university building in Dhaka, Bangladesh. To reduce resource consumption, technical systems and energy demand the design team is investigating alternative comfort strategies. The paper presents the design strategy, implementation in building simulation and analysis of thermal comfort concepts for a typical classroom. A conventional design for air conditioning according the static "comfort zone" is compared to a hybrid system design in regard to achieved comfort, required design of ventilation systems and energy demand. The thermal parameters of the building are assessed using the dynamical thermal simulation program TRNSYS 17 3D. Based on six environmental parameters the thermal comfort of the occupants is evaluated with the Standard Effective Temperature (SET) and the Predicted Mean Vote for elevated air speed (PMV_{eas}) according to the ASHRAE Standard 55-2013.

The design studies helped to develop a hybrid system comfort design which provides good fresh air quality and an excellent thermal comfort: A simple decentral mechanical system provides the room with tempered supply air of 20°C air temperature and dew point. In addition, ceiling fans provide air movement. Compared to conventional concepts of returned air with full heat recovery aiming on 26°C operative room temperature and 12 g/kg humidity ratio the energy demand is only about 75%. Both concepts provide the same comfort in terms of PMV_{eas}.

INTRODUCTION

Thermal comfort standards e.g. of ASHRAE [1] and ISO [2] are dominated by the studies and heat balance model works of O. Fanger, using the *Predicted Mean Vote (PMV)* as comfort index. Being carefully developed in mid-latitude climate regions systematic discrepancies were found, particularly in warmer zones, to explain observed thermal comfort in naturally ventilated buildings with the static "comfort zones" definitions based on the six comfort parameters in Fanger's PMV model [3]. Adaptive comfort models, developed on field studies in the tropics, as well as comparing naturally ventilated and air conditioned buildings give evidence that extended temperature and humidity ranges are acceptable [4].

Elevated air speed has long been used in practice as well as in the ASHRAE Standard 55 to offset higher temperatures in mechanically controlled indoor climates. With ASHRAE Standard 55-2013, Appendix G, a procedure for evaluating the cooling effect of elevated air speed using the *Standard Effective Temperature (SET)* is described. The *SET* can be calculated for a wide range of six environmental and personal parameters: *air temperature (T_{air}), mean radiant temperature (MRT), relative humidity (RH), average elevated air speed (v), clothing factor (clo) and metabolic rate (met).*

To evaluate the cooling effect of elevated air speed first the *SET* is calculated for the parameters and the given air speed (range: $0.15 \leq v \leq 3$ m/s). In a second step the air speed is replaced by still air (0.15 m/s) and an adjusted average air temperature is calculated to achieve the same *SET* as before. With this adjusted average air temperature, the air speed of still air and the four remaining parameters the *Predicted Mean Vote for elevated air speed (PMV_{eas})* is calculated and can be used for comfort evaluation and comparison [1, Appendix G and B]. This procedure was implemented into building simulation. To be useful for the evaluation and design of alternative comfort and climate concepts the method is implemented in a way that the required air speed to create the same perceived comfort - or in other words the same *Predicted Mean Vote for elevated air speed (PMV_{eas})* as for the reference case - could be determined by the simulation code representing an occupant controlled fan to increase air speed as required. An exemplified tool including PMV_{eas} is the Internet CBE Thermal Comfort Tool developed at the University of California Berkeley [5].

To summarize: the implemented procedure allows evaluating the different design strategies with the 7-point scale of thermal sensation, defined as follows: hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cool (-2), cold (-3) and compare with the analytical comfort zone model of Standard 55-2013, chapter 5.3.2. Compliance is achieved when $-0.5 < PMV_{eas} < 0.5$, which is equivalent to a satisfaction of 90% of the occupants with the environmental conditions.

THE PROJECT

The non-governmental organization BRAC is currently planning a new university building in Dhaka, Bangladesh. BRAC is particularly interested in a sustainable building concept which creates best comfort in the local context. The architects commissioned are WOHA, Singapore, who are experienced in the design of naturally ventilated buildings in the tropics. For comparison study, the School Of The Arts (SOTA) in Singapore, also designed by WOHA Architects, serves as a role model: Wherever appropriate, the classrooms are naturally ventilated and thermal comfort is enhanced with ceiling fans to elevate air speed in the occupied zone. The passive building design and the elevation of the classrooms above ground reinforce natural ventilation by prevailing wind directions. Air conditioned zones are reduced to a minimum.

To cross check the proposed design strategy and to familiarize the design team with the strategy evaluating thermal comfort with the *SET* and *PMV_{eas}* a short comfort survey was made at SOTA. The classroom (Figure 1) was surveyed for an ambient air temperature of 30°C and an air humidity ratio of 17.5 g/kg. This represents a typical outdoor climate of Singapore's summer period. The measured local air speeds are in the range of 0.4 to 1.0 m/s (Figure 1). The results showed that for the given parameters the environment is comfortable (none of the occupants wanted to change clothing nor to change air speed). The survey provides an additional confirmation that the proposed design parameters *SET* and *PMV_{eas}* can be used for comfort evaluation in the tropics. Mentioned work on adaptive comfort models underlines this conclusion [4].

Occupancy
23 pupils
1 teacher

Room geometry
Area: 80 m²
Height: 3.5 m

Doors
operable, on two sides of the room

Windows
opposite on two sides of the room

Six ceiling fans

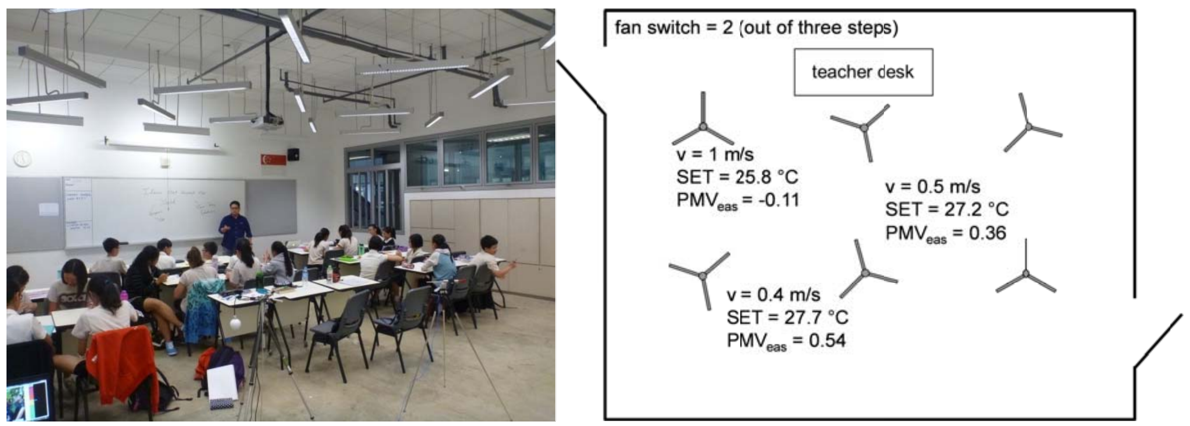

Figure 1 left: classroom at SOTA; right: local air speed and comfort measurements, top view plan of the classroom [6].

Compared to Singapore, Dhaka's summer climate differs significantly in terms of humidity ratio and ambient air temperature (Figure 2).

As a consequence, the BRAC University comfort design could rely on natural ventilation for the winter period, but not for the hot and humid summer time.

Thus, based on the original design concept of the SOTA classrooms energy efficient comfort design strategies for a typical classroom of BRAC University have been compared, analyzing the difference between a conventional fully air conditioned and a hybrid system concept for the Dhaka summer period.

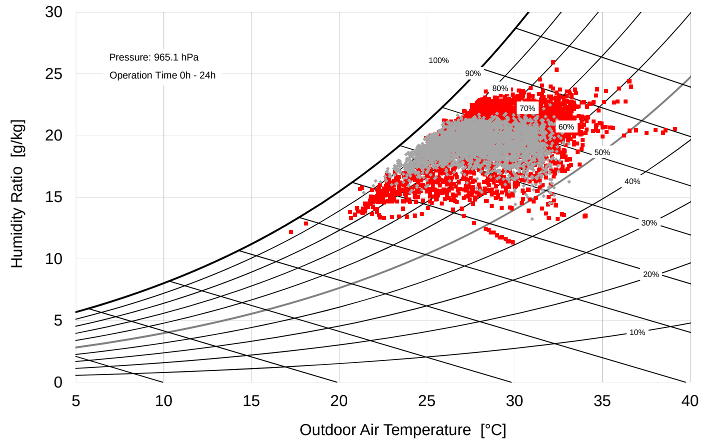

Figure 2 Psychrometric chart with IWEC Singapore (grey) and SWERA Dhaka (red) summer climate data

IMPLEMENTED BUILDING SIMULATION METHOD

All environmental parameters (room geometry, internal and external loads, occupancy, buildings physics, ventilation, cooling power, etc.) are modelled with the dynamical thermal simulation program TRNSYS 3D on an hourly base. In a second step the thermal comfort is modelled based on the calculated environmental parameters and the control strategy of the fans using the *Engineering Equation Solver (EES)* where the codes for SET and PMV_{eas} have been implemented according to the ASHRAE Standard 55-2013.

The simulation model

The thermal simulation work was carried out for a typical classroom model of BRAC University in Dhaka with dimensions 9.0*9.0*3.1 m³. The east and west façades are 30% glazed, semi-outdoor hallways affiliate on the outside. The hallways are naturally shaded by façade plants. For a typical university schedule, the classroom's operation time includes weekdays from 07:00 to 17:00, fully occupied by 40 students. Sedentary activity with 70 W sensible and 65 g/h (40 W) latent load per student as well as adaptive clothing from 0.5 to 1 clo were assumed. In Table 1 the major characteristics of the classroom model are summarized.

Table 1. Simulation settings for the classroom model used in TRNSYS 17 3D

Climate, Shading & Geometry		Time Settings & Occupants		Internal Loads & Air Supply		
Climate Data	SWERA Dhaka	Time	May - Oct	Occupants	110	W/Pers
Shading West/East	External	Operation Day	07:00 - 17:00	Electrical Loads	5	W/m²
Classroom Area	81 m²	Total Operation Hours	1320 h	Artificial Light	10.5	W/m²
Classroom Volume	251 m³	Occupants Number	40	Air Supply	30	m³/Pers

Conventional comfort design with full air conditioning and fan coil cooling

In the tropics, the typical climate concept for offices and public buildings is closed façades combined with full air conditioning. So for the conventional case, a climate concept with conditioned supply air and heat recovery from the returned air combined with fan coil cooling was chosen (Figure 3). Aiming at 26°C operative temperature and 12 g/kg humidity ratio, this system fulfills the conventional "static" PMV comfort standard. For evaluation the following design assumptions are made: Fresh air supply is set to 30 m³/h*pers in order to achieve good air quality for an university environment. Fresh air is

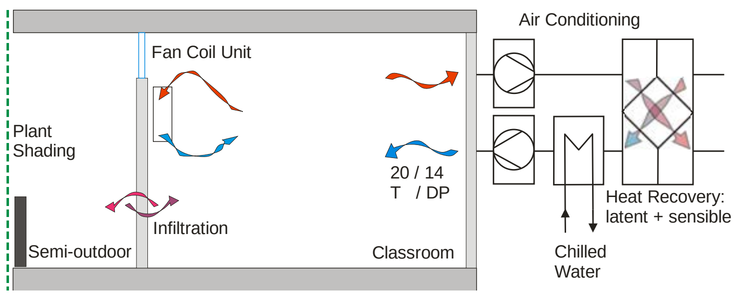

Figure 3 Conventional comfort design with full air conditioning and fan coil cooling

supplied with 20°C and a dew point temperature of 14°C (10 g/kg), the latent and sensible heat recovery is 75%. The fan coil unit is designed to cool the room air to maximum 26°C operative temperature and to keep room air humidity ratio below 12 g/kg. Infiltration is set to 0.2/h. In this system the air conditioning is introducing fresh air, cooling, dehumidification and air circulation (to be distinguished from the air movement in the hybrid system: see next sub-chapter).

Hybrid system comfort design, decoupling cooling from air movement, with tempered air and elevated air speed

For the hybrid system comfort concept fresh air is supplied with also 30 m³/h*pers to the room. The supply air is tempered, meaning cooled to 20°C (resp. 22°C) air temperature and dew point (equal to 14.7 resp. 16.7 g/kg) only. The supplied air is pressurizing the room and spilling over to the hallways, which minimizes infiltration (Figure 4). The condensate from the decentralized supply air units is used for irrigation of the façade plants.

To establish constant comfort, six ceiling fans with controlled air speed are used in addition. Air velocity is automatically elevated in two steps from 0 to 0.7 to 1.2 m/s, if perceived comfort exceeds 0.5 PMV_{eas}. This is set to be in line with recommended limits for air speed of sedentary work (0.7 m/s) and maximal air speed under occupant control (1.2 m/s) according to ASHRAE Standard 55.

For further comparison a design without any mechanical ventilation but natural window ventilation (air change rates, driven by thermal boundary conditions, range from min. 4.8/h to about 10/h) and elevated air speed with ceiling fans has been compared (see next chapter).

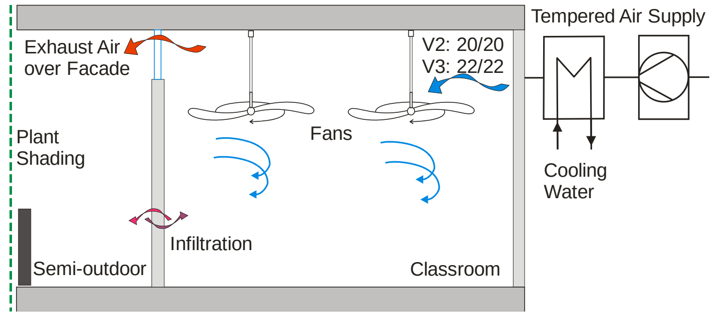

Figure 4 Comfort design with tempered air and elevated air speed

RESULTS AND DISCUSSIONS

In Table 2 the four variants of different comfort designs are compared. The first variant V1 stands for the conventional comfort concept of full air conditioning and fan coil cooling. The variants V2 and V3 are based on the comfort design of tempered air and use of fan. V4 represents the fully natural ventilated design with no air tempering but use of fans.

Table 2.Variants of comfort design for a typical classroom

Variant	Ceiling Fan	Fan Coil Unit	Mechanical Ventilation T_{supply} [°C]	Mechanical Ventilation $T_{dewpoint}$ [°C]	Heat recovery [%]
V1	No	Yes	20	14	75
V2	Yes	No	20	20	-
V3	Yes	No	22	22	-
V4	Yes	No	-	-	-

All four variants have been evaluated on the same basis with PMV_{eas} for the purpose of comparing the achieved comfort. Figures 5 and 6 show that for V1, V2 and V3 the achieved PMV_{eas} is in the range of 0.2 to 0.5. Thus, those variants provide excellent comfort. In contrast, V4 provokes uncomfortably warm conditions, even though fans are at high air speed of 1.2 m/s (Figure 8). Its PMV_{eas} increases up to typically 2, in maximum to 3. Thus, V4 is not discussed any further.

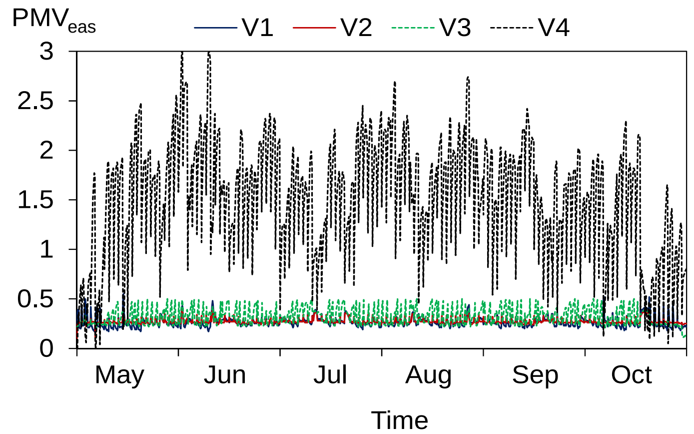

Figure 5 PMV_{eas} curves of comfort design variants over Dhaka's summer period

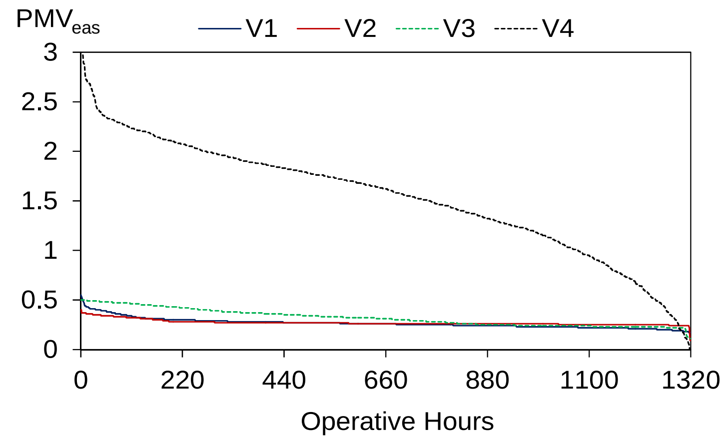

Figure 6 Sorted PMV_{eas} curves of comfort design variants over Dhaka's summer period

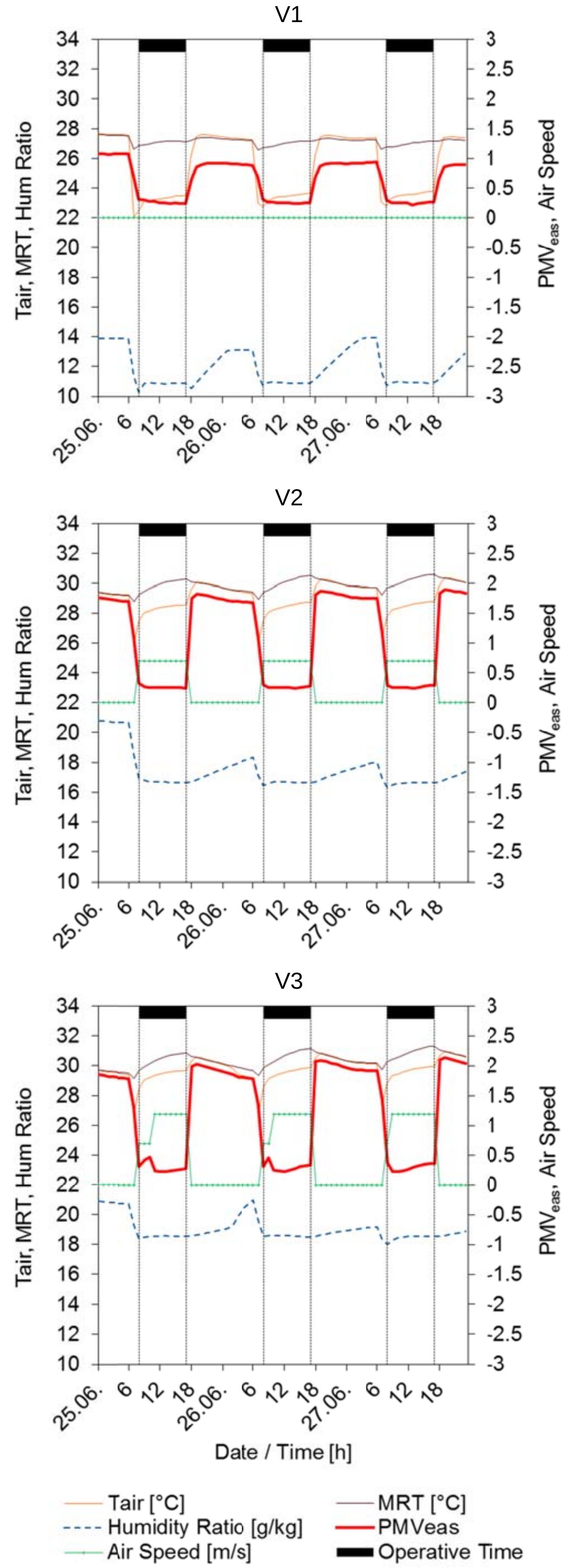

Figure 7 Design day chart showing the achieved PMV_{eas} and its major parameters for the compared variants [7]

Figure 7 on the left gives a detailed comparison of the parameters' interaction for variant V1, V2 and V3. Three design days in June were chosen to represent a typical summer situation in Dhaka. The results from the thermal simulation were used as input parameters for comfort calculation [7]. T_{air}, MRT and humidity ratio are plotted on the left ordinate. Determined fan step as well as resulting PMV_{eas} are shown on the right scale. Black plotted bars at the diagram's top indicate the occupants' operative time.

V1 leads to average values for T_{air} with 23.5°C and MRT with 27°C, and to a reduced average humidity ratio of 11 g/kg (Figure 7, diagram at the top).

In contrast, the hybrid variants allow higher T_{air} and MRT values between 28°C and 31°C and higher humidity ratio of 16 to 18 g/kg. The impact of high temperatures and humidities is compensated by elevated air speed causing comparable PMV_{eas} values in the range of 0.2 to 0.4 during occupation.

The comparison of V2 and V3 shows that a fan speed of maximal 0.7 m/s is sufficient for V2, whereas the slightly warmer and more humid environment in V3 requires 1.2 m/s for most of the operative time in order to keep the PMV_{eas} at the same range (Figure 7, middle and bottom diagram). To provide the same comfort in all variants with fan, the six ceiling fans run constantly during the 1320 h of occupation (Figure 8).

V2 establishes good thermal comfort while constantly using the lower fan step of 0.7 m/s at all 1320 hours of operative time. With V3 a higher average air speeds is necessary due to the reason mentioned above. Almost one third of operative time the higher fan step of 1.2 m/s is required. If this would be acceptable to the users the energy savings would be about - 42% (Figure 9).

But as ASHRAE 55 recommends limiting air speed for sedentary activity in the occupied zone, V2 with 0.7 m/s air speed is the preferred variant even though the energy savings are less with - 25%.

The comparison of the variants' energy demand (Figure 9) gives evidence that substantially less mechanized concepts can achieve significant energy savings even though no heat (cold) recovery is installed.

As room air temperature and humidities are higher compared to conventional systems additional sensible and latent heat recovery would be less effective. For V2 cooling energy could be reduced e.g. from 66 to 45 kWh/m²a, but a full sensible and latent hreat recovery system (75%) would be required.

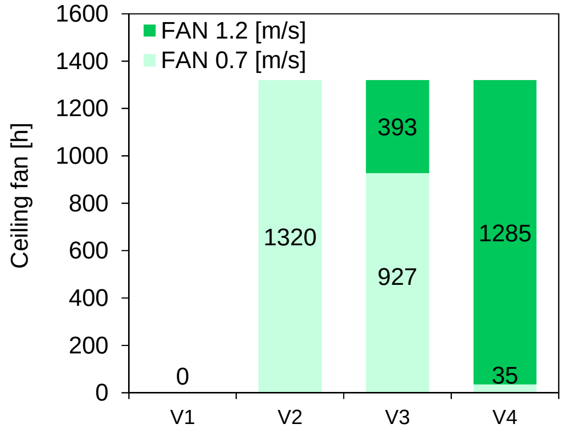

Figure 8 Running hours of fans of each variant, accumulating to 1320 h of total operative time

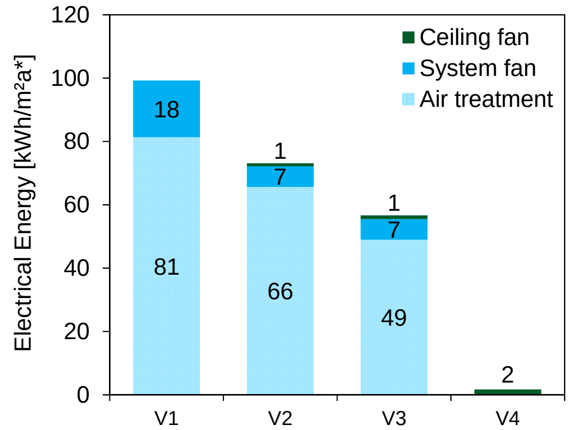

Figure 9 Electrical energy demand of each variant for ventilation, cooling and dehumidification (COP 3)

CONCLUSIONS

The paper's purpose is to investigate whether a hybrid system comfort design can lead to significant energy savings while providing equal comfort compared to the conventional concept of full air conditioning and fan coil cooling.

Methodology, implementation in building simulation, and analysis of thermal concepts for a typical university classroom in Dhaka, Bangladesh, have been carried out. The implemented method based on ASHRAE's SET-PMV comfort evaluation for elevated air speed proved to be a powerful tool to explain thermal comfort achieved with 100% fresh air supply of tempered air and the use of ceiling fans as typically installed.

Based on the results, a hybrid system comfort concept with dedicated fresh air supply is proposed which provides good fresh air quality with 30 m³/h*pers and excellent thermal comfort. A simple decentral mechanical system is proposed to supply the fresh air at 20°C temperatures and dew point. In addition, ceiling fans provide acceptable air movement during operative time. Compared to the conventional concept of conditioned air with full heat recovery aiming on 26 °C operative temperature and 12 g/kg humidity ratio, energy savings are about 25%.

The supply air systems can be installed decentral and operated per room in case of occupation only. Typical installations for mechanical rooms with central air conditioning systems, heat recovery, insulated supply and return air ducts in false ceilings, vertical shafts etc. are not required. The substantially lighter hybrid system will have lower investment costs of the system itself as well as for the building as less space is used for the air handling systems and will allow a more simplified building envelope design and thermal zoning of the university building.

It is to be noted that achieved comfort of the systems analysed is comparable, while their influencing environmental parameters configure in two complete different ways: the hybrid system variant provides comfort with high operative temperatures and high humidity compensated by elevated air speed, whereas systems with full air conditioning and fan coil cooling run on low operative temperatures and low humidity without elevated air movement.

While similar built examples of hybrid systems exist, the paper's outcome fills the gap of a missing methodology to assess hybrid comfort designs in tropical climates. The method proved to be useful for these design evaluations.

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LEARNING ENERGY SYSTEMS: An holistic approach to low energy behaviour in schools

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ABSTRACT

Existing buildings are aligned with substantial energy use. Energy modelling is failing to produce an accurate prediction of the energy needed to operate buildings, particularly in the education sector. Schools and higher education estates often use 50% more electrical energy than the design models show. Much of this is associated with what is termed 'unregulated' energy, in other words, energy associated with unpredicted use of the building.

Working with sets of energy data, school pupils, teachers and building managers were involved in an action research project around the theme of lighting energy. This led to a reduction in energy use by lighting of 15%. Lighting control systems and education and awareness of energy use both contributed to this reduction. The study considers the benefits in financial terms. The relatively small gains offer significant potential over the lifespan of a school building. The wider benefit is in the involvement of building users in the management of their energy use.

INTRODUCTION

Understanding the way people use energy is seen as the key to improving energy performance in buildings. This paper presents a pilot study examining an interactive response by school children to the management of lighting in their school. It is part of a wider research project exploring the integration of the 'human' into the energy management of school buildings. The pilot study combined the use of energy data, and lux level measurement with action research in the school building.

It is estimated that lighting for buildings consumes 19% of global electricity generation (Grinfeld and Grinfeld 2009). Improved energy efficiency of lighting has resulted in an overall reduction in this load. UCD-OPET (1994) identifies 12% of energy use for lighting in typical UK schools in the 1990s. This had reduced to 8% in 2012 (Carbon Trust, 2012) due to improved lighting efficiency, however this equates to 20% of the energy costs of the building. This is why it is so important to reduce the amount of energy we use in for lighting (Ryckaert, Lootens, Geldof, & Hanselaer, 2010). Artificial lighting is dependent on electricity and has the highest CO_2 emission factor of energy sources (compared to gas oil and coal) at 0.422 $kgCO_2/kWh$ which further emphasises the need for reducing the energy used for illuminating our buildings (Lee & Guerin, 2010). As well as the cost to the environment, is the cost to society in energy bills. Reducing the energy use of public buildings will reduce the financial burden on local government (Di Stefano 2000).

The amount of energy used for lighting in public buildings is affected by two primary factors: the design of lighting system; and the users of the building and their attitude towards the energy. This study focuses on a primary school building in Scotland, and encompasses an overview of the types of lighting control currently used in existing school buildings. By involving building occupants, the study examines how these lighting controls can be better used and managed by building occupants to reduce their consumption of electricity, and if modification of building users' behaviour and attitudes towards energy use can reduce the overall energy consumption of the building.

LIGHTING CONTROL

Well designed and controlled lighting systems can reduce the energy use of artificial lighting by up to 40% (Grinfeld and Grinfeld 2009). For optimum energy efficiency a lighting control system must be designed so that it generates the required lux levels, delivering lighting using the least amount of energy (Karlen, Benya, & Spangler, 2012). Control systems have become more sophisticated and range from individual control, to highly sensitive computer operated building systems. This range of systems is found in the school being used for this study.

Local manual switching usually comes in the form of wall switches that can be controlled by building users with on/off or dimming switches (Simpson 2003). Relying on manual switching can lead to a high amount of wasted energy if occupants do not control them efficiently (Rawlinson 2008). Local manual switching is used in the classrooms in the school being studied. Centralised switching can be operated automatically at certain times in the day relating to the operating hours of the building (Wall and Everest 2003). Manual switching is still possible with this system to override automatic settings. If the system is well designed, studies show that few occupants will use the manual override (Grinfeld and Grinfeld 2009). This type of control is used in the corridors and assembly halls of the school but the manual override function is kept locked and can only be operated by the janitors.

Occupancy sensors are used to automatically: turn lights on when a space is occupied; keep lights on while the space is occupied; and turn off the lights once the space is no longer in use (Simpson 2003). The lights will be automatically turned off again after a definable period of inactivity. A Post Occupancy Evaluation (POE) carried out by Buro Happold (engineering consultancy company) on five schools built in the UK between 2002-2005 revealed that the use of PIR sensors saved 30-40% compared to manual switching (Pegg 2009). This study found that general circulation lighting was the worst managed, especially in areas such as atriums. This is due to the space not being 'owned' by anyone, therefore responsibility for the operation ofthese lights needs to be addressed (Pegg 2009). It is very important for building designers to think about maximising the use of daylighting when designing a building (Loe 2009). Photoelectric lighting controls (daylight linking) can either be an on-off system or a dimming system (Grinfeld and Grinfeld 2009). This type of control is present in the classrooms of the school.

Programme Logic Controllers (PLC) are centralised lighting management systems that control a whole building e.g. a school (Grinfeld and Grinfeld 2009). They consist of a computer based system that can control a combination of presence detection, daylight linking, timed and manually operated lighting systems to provide optimum control, tailored to a specific building and its users needs (Rawlinson 2008). PLCs in conjunction with a mixed manual and automatic control system will use energy most efficiently as long as they are designed to be user friendly (Loe 2009). They are also used in lumen maintenance as a new lighting system may be over specified, therefore it can be dimmed initially and power can be increased over time as the lamps lose light (Grinfeld and Grinfeld 2009) to prolong their life. The school studied has a computerised PLC system (Philips Light Manager) which allows alterations to be made to lights in the school that are controlled by automated PIR, daylight linking and timed systems.

BUILDING OCCUPANT BEHAVIOUR

The behaviour of building users can have a large effect on the amount of energy that the building consumes (Hori, Kondo, Nogata, & Ben, 2013; Masoso & Grobler, 2010). Newborough and Probert (1994) take the strong view that a lack of awareness in how energy is consumed is illiterate and apathetic. AI-Mumin *et al.*(2003) makes a statement that concurs with these views saying that 'energy-unconscious' behaviour of building occupants can lead to an excess in energy consumption. Zografakis (2008) holds the view that young people need to be properly educated on energy saving matters so that our future energy use will bereduced and that the way to do this is the education of students throughout their school life to instil an 'energy saving culture' (Faiers, Cook, & Neame, 2007; Zografakis, Menegaki, & Tsagarakis, 2008), thus creating a more energy literate society (Newborough & Probert, 1994).

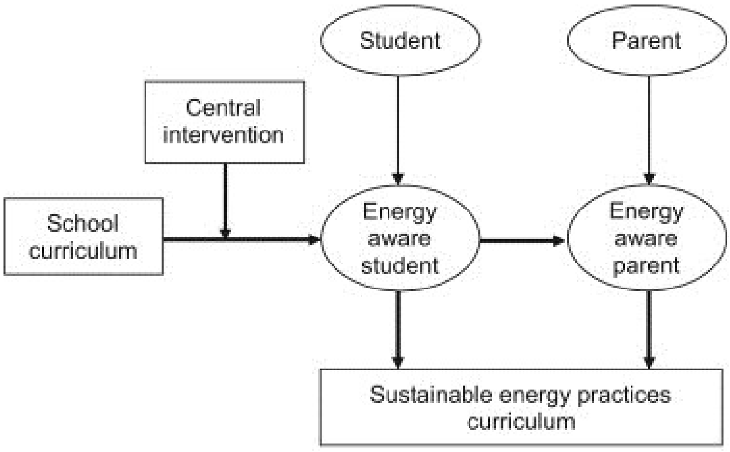

Figure 1: The effects of energy related education in society (Zografakis et al. 2008)

Figure 1 demonstrates how energy education leads to a higher understanding of the need to save energy and encouraging energy efficient behaviour. Although buildings consume the most energy during the day, often the most energy is wasted when the building is unoccupied. This is due to users leaving lights on overnight when they are not needed (Masoso & Grobler, 2010). There is a great need for building occupants to be more energy aware and learn to switch off lights and appliances when they are not being used, to reduce energy wastage (Al-Mumin, Khattab, & Sridhar, 2003; Masoso & Grobler, 2010).

The attitudes and behaviour of building occupants can undermine energy efficient building systems and technology and the two must work in harmony for significant reductions in energy use to be realized (Hori et al., 2013; Masoso & Grobler, 2010). At the same time building designers must gain accurate knowledge of how a building will be used to tailor the design to the users to achieve maximum energy efficiency (Carbon Trust, 2012).

The advantages of behavioural change through education are numerous (Dias, Mattos, & Balestieri, 2004). The potential energy saving could be more than is possible with just energy efficient equipment and systems. It is relatively very cheap and can be applied to any building new or existing (Masoso & Grobler, 2010). They make the argument that to improve energy efficiency; we should concentrate more on improving occupant behaviour and attitudes through education in energy awareness, rather than solely focusing on energy efficient technologies. Many lighting systems in public buildings, such as schools are very complicated. Even with a well designed system, for a building to reach its maximum energy efficiency it is necessary to have energy aware building users (Winterbottom & Wilkins, 2009).

ACTION RESEARCH IN LIGHTING USE

The study involved a group of school children in an action research project associated with lighting in their school. Involving school children in the study helps us see energy use from the eyes of the child. This user group offers a perspective that is often omitted from building management strategies in schools. The opportunity to engage children in the active management of energy use in their schools presents a novel response to the need to reduce energy, and fundamentally, it increases the pool of participants with responsibility for energy use.

Methodology

The research was designed to test two propositions: the behavior and attitudes of staff and pupils at the school will change in response to learning about how lighting uses energy; and that involving building users in the control of the lighting system will lead to a reduction in energy use. Recognition that this was about problem solving, led to an action research approach. This involves interaction to improve the situation, and this pro-active approach offered efficient empirical data collection, vital to the evaluation of the study (Costello, 2011).

The first visit to the school, led by the Facilities Manager, involved quantitative data collection on the lighting system of the school. This included lamps, luminaries and control systems to allow assessment of the energy efficiency of the current lighting system and to see if the hardware and technology could be improved. This was followed by the first phase of the 'lighting use survey'. Another visit to the school, led by the deputy head teacher, enabled qualitative data to be gathered relating to the energy saving attitudes and practices of the school, and an 'energy awareness presentation' to inform the whole school about the lighting study. This was followed by the second phase of the 'lighting use survey'. Figure 2 illustrates the action research process.

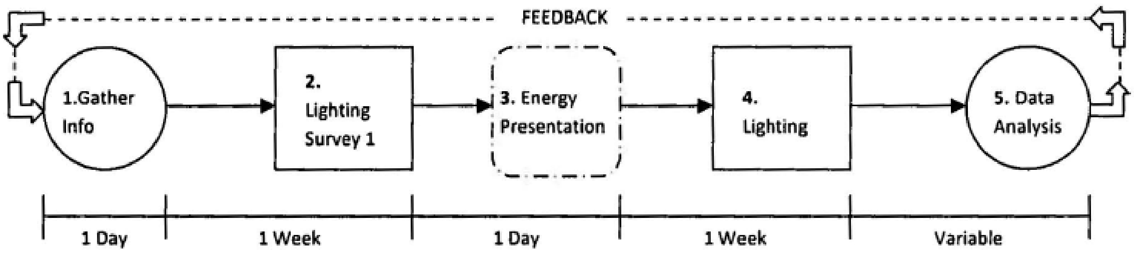

Figure 2: Action Research Process

The action research involved pupil members of the Eco-Committee undertaking the 'lighting use survey' over two separate weeks. Four areas of the school were chosen for the study to capture a range of lighting systems: a general classroom; a science room; the dinner hall; and a shared seating/circulation area. The study was carried out before and after the 'energy awareness presentation' to enable the impact of this session on energy behavior to be gauged.The survey was set up to record three sets of quantitative data:

1. If the lights were on or off at hourly intervals throughout the school day from 9am until 4pm Monday to Friday.
2. If the room was in use during these times.
3. The lux level. (meter placed on table in centre of room, for every reading)

Data from the first phase was used in the 'energy awareness presentation', delivered at a school assembly to all pupils and staff at the school. This provided pupils with information about energy sources both renewable and non-renewable and how we consume this energy. The presentation was designed for primary school children in accordance with advice in the paper '*EnergyEducation*' by Kandpal & Garg, (1999). Repeating the 'lighting use survey' following the presentation meant that changes in awareness and attitudes to lighting use could be evaluated in terms of actual decreases in lighting use.

Action Research results

Two sets of quantitative data were produced. The first week shows normal lighting usage in the selected areas of the school. The second week demonstrates lighting use after problem solving action in the form of an educational presentation. This allows simple measurement to determine if the change in behaviour of the occupants could have a significant effect on reducing the energy use of the school from lighting. The four rooms used in the study offer distinct use patterns. The Dinner Hall and Shared Area are used occasionally by large numbers of pupils and are not associated with any particular class group. The Classroom is occupied by the same group of children for the majority of the school week. The Science Room is used occasionally for specific class activities by small groups of pupils led by a teacher.

The action research led to a reduction in energy use from lighting in all areas apart from the Dinner Hall (Figure 3). The graphs show the number of hours that the lights were on and the number of hours that each space was occupied. The significant reduction in energy use is seen in the rooms that are occupied by defined groups (classes). The two large areas with occasional use showed small improvements in redundant use of lighting, and demonstrate the difficulty faced in managing energy consumption in spaces that are not 'owned' by their occupiers.

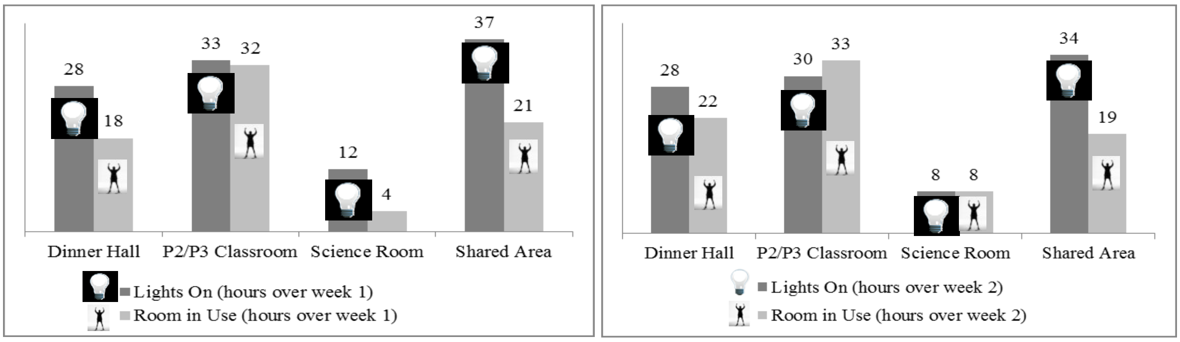

Figure 3: (a) Light and Room Use in Phase 1 (b) Light and Room Use in Phase 2 (numbers represent hours that light is on or room is occupied)

Room Area analysis

The dining area is controlled by a key operated switch box that is kept by the janitors. This meant the energy use could not be directly controlled by the room users. This seems to be linked to energy waste (lighting on in an empty room) at 36% in the first week's study. Redundant light use decreased by 15%. The lighting use was identical over the two weeks but the physical use of the room increased corresponding to an increase in the lighting efficiency (lighting on in a room that is being used) from 64% to 79%, however this cannot be correlated with energy saving behaviour. The lux level was above the recommended 500llux for dining halls in CIBSE (2002) at an average of 770lux during the both weeks of the study. Therefore daylight linking would provide a direct reduction in energy use.

The control system in the classroom is quite advanced as there are three sets of lights. The sets of lights at the window and the corridor side of the classroom are controlled by two daylight sensors at either side of the room. If there is the required lux level of 500lux (CIBSE) then the lights will switch off in that area to save energy. The main on/off switch is located in the classroom and is therefore user controlled. The energy use in this room was very good in the first week's study, 97% of the light was being used and only 3% was being wasted. However in the second week an improvement was made as there was no wastage of light and the room was in use for three hours when the lights were turned off, as daylight would supply the required lux level. The room also used 3 hours less energy in the second week with the similar amount of use. The lighting system is quite advanced. The luminaries are energy saving models with high frequency ballast. However the control system could be improved by the daylight linked lights being dimmed rather than turned completely off. This will save more energy, extend the life of the lamps and be less distracting to room users (Roisin et al. 2008, Li et al. 2010). The average lux level over the two weeks was 510 lux which is very close to the recommended 500lux for classrooms.

The control system in the science classroom is very similar to the P2/3 Classroom as there are three sets of light. The main lighting switch is user controlled. The lighting wastage from this area in the first week was a relatively high at 67%. In the second week 4 hours less lighting the lights were only used when the room was occupied. As with the P2/3 classroom, the lighting system in the science room is quite advanced. The control system could be improved by the daylight linked lights with a dimming setting as recommended for the P2/3 classroom. The average lux level over the two weeks was 415 lux which is slightly below the recommended 500 lux for classrooms.

The lights in the shared area are controlled on a simple series circuit. These lights are on the same automatic control as corridors, and will be 'held on' as long as lights are on in a room in that area. The overall energy saving in this area over the week was 3 hours but the energy wastage stayed at a high 43%. The lighting system is quite advanced. The luminaries are energy saving models with high frequency ballast. However the control system could be improved by the daylight linked lights as the shared area is located beside two large windows. The average lux level over the two weeks was 554 lux which is much higher than the recommended 200 lux for shared circulation space. This means that the lights could be dimmed to save energy (Li et al. 2009).

Overall in week 1 of the study the four rooms in the study had lights on and the room not occupied for 32% of the time. The use of lighting when not required (i.e. day lighting adequate or room not occupied) reduced by 15% in week 2 of the study.

Cost Analysis

Table 1 shows the savings per week which were calculated by multiplying the power load for the room in watts (electricity use when lights are on) by the by the number of hours the lights were used. This gives an amount of power used in watts which is then divided by 1000 to give an amount in kilowatts. This is a necessary step as a buildings electricity use is measured in kilowatt hours (kWh). The amount of kWh is then multiplied by the unit rate for the school which was at £0.0671 at the time of the study.

Area	Saving from energy education/ week	Saving from dimming lights/week (-20%)	Estimated saving from daylight linking (-15%)	Total combined saving/week
Dining Hall	£0.00	£0.55	£0.41	£0.96
P2/3 Classroom	£0.21	N/A	N/A	£0.21
Science Room	£0.08	N/A	N/A	£0.08
Shared Area	£0.10	£0.22	£0.17	£0.49
Actual Savings	£0.39	£0.77	£0.58	£1.74
Total across school/week	£19.45	£15.40	£11.55	£46.39
Total across school/year	£719.49	£569.63	£427.22	£1,716.34

Table 1: Potential cost savings from lighting efficiencies

The lighting cost was then multiplied by the number of similar rooms or spaces to give a total saving across the whole school campus. This figure was then multiplied by the number of operational school weeks in the year to generate an estimated figure of yearly energy savings. Firstly the estimated yearly energy saving from regular energy awareness presentations is £719.49. This is therefore an effective energy saving measure with a low implementation cost. The lighting system is controlled by Philips Light Manager system which could dim the lights in the appropriate rooms via the computer control system. The lighting savings from dimming the lighting by 20% came in at a lower yearly saving of £569.63 which is possible with the existing lighting infrastructure and is therefore an affordable and feasible energy saving measure. Two out of the four rooms studied could benefit from daylight linking systems as they are located near windows. Although this indicates a decent saving of £427.22, this does not take into account the cost of installation. Therefore with only a small expenditure for energy awareness presentations combined with dimming lights, there is a potential saving of over £1,200 per year to be made. On top of this, if the daylight linking systems were found to be financially then even more money could be saved on lighting. The cost analysis offers realistic scenarios with commonly used equipment and control systems found in many modern buildings. The installation has a sophistication that offers the ability to respond to the lived experience and feedback on the people using the buildings with small cost implications.

CONCLUSION

Active involvement of building users in the management of buildings is shown to lead to better peforming buildings (Bordass & Leaman, 2005). This study has shown engagement with quantitative monitoring, and qualitative education, that direct gains can be made in energy reduction. The focus on lighting provided a tangible and visible energy stream that was measureable and controllable by the project participants. Involvement of school children in this action research is important to embrace the idea of energy communities and their ability to manage energy demand (Fazeli, Christopher, Johnson, Gillott, & Sumner, 2011). The reduction in lighting use experienced in this study, seems to be linked to feedback data on lighting use, combined with an educational presentation on energy.

These results show that there is a large scope for energy saving through different aspects of lighting control. This can be done by either changing how the lighting operates using the PLC or changing how the lighting is operated by changing the behaviour and attitudes of the building occupants. It also highlights that there is little or no energy savings to be made by upgrading lamps and ballasts at the moment as the school has very up to date technology.

The study provides useful insights into the effectiveness of including people in the management of complex energy systems. Modern energy infrastructure is increasingly relying on complex building management systems (BMS) to monitor and control systems. In the study building a sophisticated lighting control system is installed. The way in which it has been set up does not relate to the way in which the building is being used. The involvement of building occupants in their environment offers potential for improving the way that complex systems can operate and respond to the lived experience of these people.

This study is part of a larger project, Learning Energy Systems at the University of Edinburgh, currently exploring methods to better integrate building occupants into the management of energy in their school buildings. This study demonstrates that with small interventions, significant energy reduction is possible over the life span of a building by addressing user behavior. In this case 15% reduction in lighting use was achieved with minimal intervention or alteration to the lighting control system. This potential this offers to a wider range of energy use beyond lighting in school buildings is considerable, and this provides interesting context for further work in this area.

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Session 7D : Tools and methods/ framework

PLEA2014: Day 3, Thursday, December 18
10:25 - 12:05, Trust - Knowledge Consortium of Gujarat

Monitoring and Visualizing High Performance Building Strategies

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ABSTRACT

This paper describes the design of a system to monitor high performance building strategies and to visualize performance. The implementation of the system at a 640 m2 educational center in San Francisco is discussed, with reference to specific renewable energy systems and sustainable building strategies. A variety of off-the-shelf as well as custom sensors was specified in order to monitor these strategies specifically. Since the center uses the data for education and research, the approach to data visualization required addressing the needs of a wide variety of users. A dashboard was designed so that occupants, managers and the public could understand how the building was performing in real time, as well as at different time scales. Rather than simply graphing data, the dashboard places data in meaningful context. In addition, advanced visualization techniques are used as a complement to the dashboard to gain further insight into patterns and tendencies in building behavior.

INTRODUCTION

Building energy and environmental monitoring has many potential benefits, including helping to maintain high energy performance, providing feedback to design teams, and tracking energy use that can be controlled by occupants (NBI 2009). As low-energy design increasingly relies upon multiple strategies to provide a visually and thermally comfortable interior environment, it is critical that variables relevant to that performance are monitored. Furthermore, this understanding may be realized only if data visualizations reveal relationships that are indicative of performance, translating data into knowledge (Marini et al 2011). This paper presents a monitoring and dashboard system we designed to meet this goal.

PROJECT BACKGROUND

This monitoring project came about during the design of temporary relocation of the Crissy Field Center (CFC), a National Park Service organization focused on education and outreach. Their programs consist largely of collaborations with nearby schools to provide environmental education to supplement elementary through high school science curricula. CFC conceived of the relocation project as an opportunity to demonstrate and test a variety of sustainable building strategies. Project Frog was hired to deliver a building containing a number of sustainable features on a short construction schedule, and Loisos + Ubbelohde was an ongoing consultant to Project Frog on energy and comfort issues. The building achieved LEED Platinum certification and consists of the “cafe” and the “center" (see Figure 1). The cafe (about 130 m2) is open to the public and contains seating, counter service, and a food preparation area. Food is prepared off site, so kitchen activities are limited to refrigeration, reheating, and sanitation. The center (about 510 m2) has no public access and consists of two classrooms, a large gathering area, three open office areas, a computer lab, a small kitchen, lavatories, and several other small support spaces.

Sustainable Strategies

While a number of sustainable strategies were integrated, this paper presents selected strategies that are relevant to energy and comfort performance. The building seeks to take advantage of its location adjacent the bay in temperate San Francisco. Although conventional thought would have included air conditioning to address the potential for occasionally significant space loads, the client and project team favored the sustainability benefits of excluding air conditioning. An under floor air distribution (UFAD) system was specified to provide ventilation air and space heating. The team believed that the raised floor construction had the potential to influence space comfort via the surface temperature of the floor as well as via the air. Most spaces have ample access to daylight. Electric lighting is controlled by daylight and occupancy sensors.

A number of renewable technologies were included in the project. Solar energy was harvested for electricity and hot water heating. A 28.35 kW photovoltaic (PV) array sits on the roof and includes micro-inverters to convert DC to AC power at the module. A 9.9 m2 solar thermal collector designed to be the primary supply of hot water for the cafe. Wind energy is harvested using five vertical axis wind turbines. Lastly, a rainwater collection system gathers rainwater from the roof for use in toilets.

MONITORING

The monitoring system includes a variety of hardware components from individual sensors to a cloud-based data management server. Selection of these components related to the needs of the project. Output from renewable systems needed to be monitored, including electricity produced by PVs and wind turbines, heat collected by the solar thermal system, and rainwater used. A weather station including solar radiation, wind speed, and rainfall, was also specified in order to understand available resources. To address envelope and mechanical system performance, energy meters were specified to indicate flows of electrical energy and natural gas, and environmental sensors were specified to monitor comfort conditions. Specific components of comfort were prioritized for a variety of reasons. These included air temperature, radiant temperature, humidity, and carbon dioxide. We identified a variety of sensors to meet these requirements. These included current transformers and electrical meters, gas and water meters, and interior humidity and carbon dioxide sensors. We chose to build custom temperature sensors since these gave us the ability to embed sensors at locations not possible with off-the-shelf products (see Figure 1). In order to collect data from all these sensors, we built a hierarchical system of nodes to systematically convert signals to variables, collate variable measurements within a consistent timestamp, upload data to a server, check for errors, and store data. Wherever possible, we used widely available products and technologies, while resorting to custom solutions where needed.

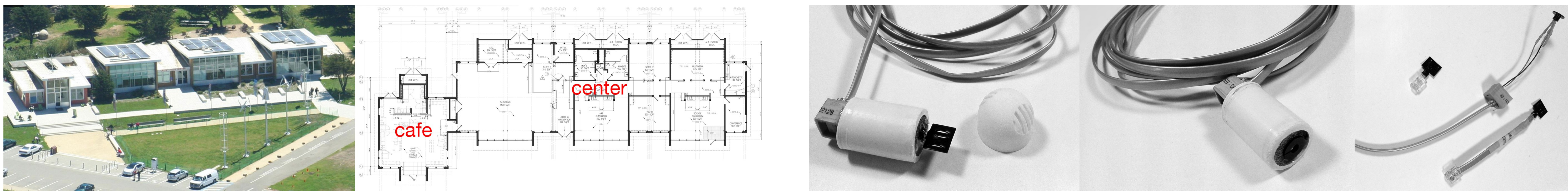

Figure 1 *Aerial view of Crissy Field Center, plan (left); custom sensors for air, wall surface, plenum air, floor surface, and duct temperature (right).*

DASHBOARD

The requirements of the dashboard were born of the educational mission of the client as well as the desire of all team members to make the performance visible. The team imagined a variety of user types, including students at the center, teachers, interested members of the public, facilities managers, administrators, and specialists in high performance buildings. Through an iterative design process, we sought to make data come alive by providing quantitative and qualitative context to data. Several critical features emerged from this process that relate to data representation:

1. Data would be represented at multiple levels of detail, starting with a high-level summary to provide a single assessment of performance and to engage users (see Figure 3).

2. For more detailed time series representations of data, multiple related variables would be shown on a consistent time scale to facilitate comparisons between variables (see Figure 2).

3. Users would have the ability to look at data across different time scales, allowing them to study trends that could occur on different time scales, from a day to a year.

Figure 2 *Dashboard interface showing comparison of several variables on a consistent time scale.*

4. Graphs would be specifically designed for the variables displayed. For example, stacked area graphs show trends in energy end uses (see Figure 2), and line graphs showing temperature relative to a comfort zone (see Figure 4).

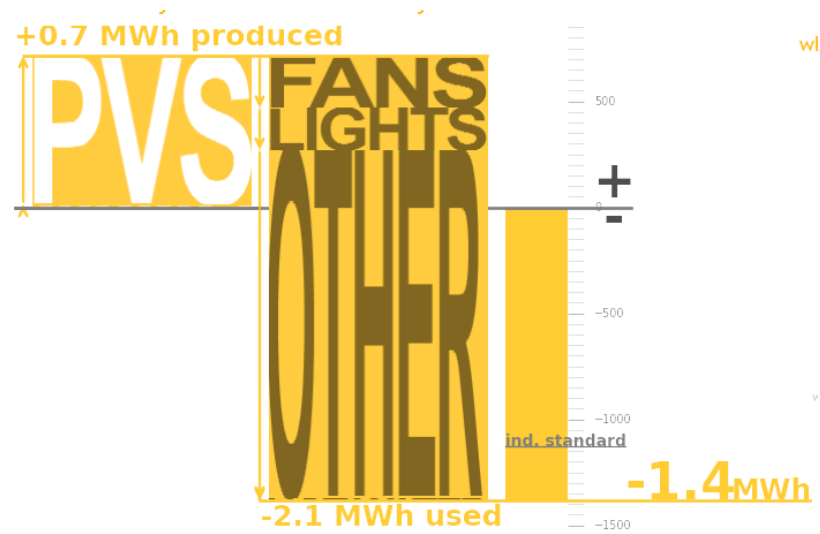

Figure 3 *Summary graph showing net energy performance and end uses.*

The Dashboard in Use

To more fully illustrate how the dashboard is used, we present some observations made and lessons learned from the dashboard in use. We note not only the usefulness but also some limitations of this fixed set of representations. As the dashboard allows users to answer questions, it also leads to more questions that require an additional, deeper and more customizable layer of data visualization for the most advanced user.

An energy summary graph scales text height to emphasize end uses that are more significant (see Figure 3). The graph shown here is typical of multiple timeperiods, with PVs producing so much more energy than the wind turbines that the bar representing the wind turbines is all but invisible (it is located beneath the section labeled "PVS"). Also, we see that "OTHER" accounts for most of the electrical load. Subsequent inquiries have revealed opportunities for optimizing energy use, such as replacing an industrial refrigerator that is lightly used, or working with the IT department so that all computers don't have to remain on all the time just for an infrequent software update.

A series of graphs of related variables comprises detailed view. In Figure 2, we begin to see the relationship between PV production and available solar radiation. We again see that the PVs outproduce wind turbines, but it is not clear if this is a fair comparison of the two technologies. A variation of this view also begins to reveal that more electric lighting energy was used during the more cloudy day, indicating that the building shows a response to the availability of daylight.

Finally, figure 4 shows a view into the thermal performance of the space. Here, it is clear that the floor surface temperature remains more consistent and cooler than the air temperature. With all of these trends, we have learned something about how the building was performing during a particular period in time, but we might also ask more specific questions about how these trends fit into the yearly performance of the building.

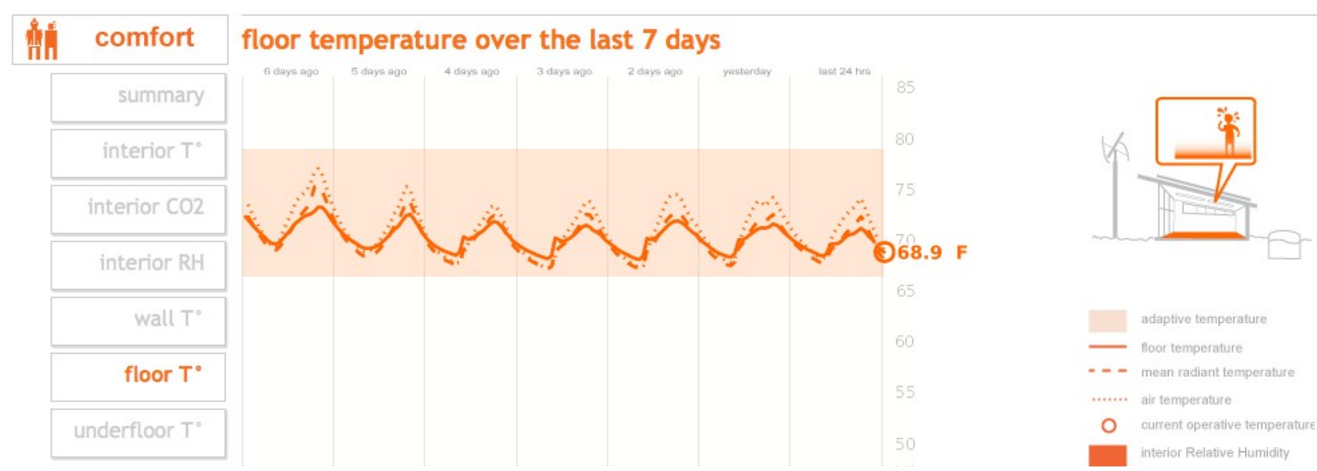

Figure 4 *Detailed temperature trend graph showing comfort zone, air and surface temperatures.*

ADVANCED DATA VISUALIZATION

Advanced dashboard users might ask questions that require a more sophisticated approach to data visualization in order to reveal behaviors that can help answer questions. Since the monitoring system allows for retrieval of data in an organized format, it may be explored using open source tools. The following graphs show examples of such an exploration of the data using the Pandas, Matplotlib and NumPy Python libraries within the iPython Notebook environment.

Figure 5 shows the electric lighting performance of the cafe over the course of the first year of data. This yearly representation graphs points colored by a mapping of data to color value intensities and located with hour of the day versus day of the year so that larger trends in the most fine-grained data may be revealed. We note that electric lighting use in the center seems to change with occupancy and availability of daylight, as opposed to the cafe that operates purely based on a regular daily schedule. In the center, note the weekday/weekend patterns and reduced use during summer months.

Figure 6 combines two variables to study trends in air versus surface temperatures. The patterns show strong seasonal variation, with the floor surface warmer during winter when the system cycles in heating mode, and cooler than the air temperature during the warmer months. This behavior is noteworthy since it shows not only that the floor surface could be helping occupants feel warmer in the winter, but it also has the potential to allow them to feel cooler in the summer without mechanical cooling.

Finally, Figure 7 begins to compare the PV and wind turbine technologies by showing the relationship of the output of each system relative to environmental conditions as a scatterplot. Output is normalized by graphing percent of capacity. The predictability and consistency of the PVs becomes readily apparent, as does their ability to produce up to about 85% of their rated capacity. While this definitively shows the poor performance of the wind turbines relative to their rated capacity, more research is needed to identify the reasons for this before conclusions can be drawn regarding this technology.

We note that we gain information using these more advanced data visualizations through abstraction. The context for each graph has become removed in order to reveal behavior. For this reason we see these techniques as fundamentally complimentary to the dashboard and not a replacement.

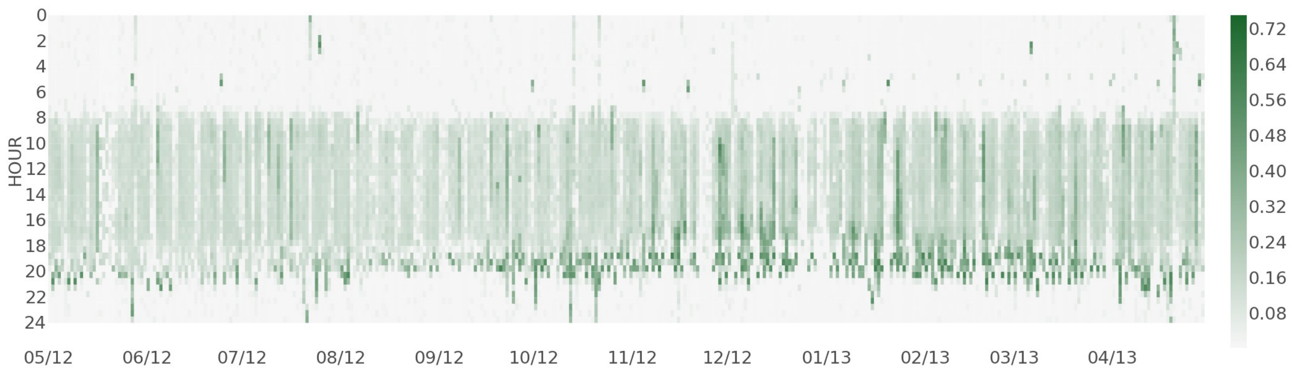

Figure 5 *Hourly graph studying the electric lighting performance in the center for the first year of available data. (W/ft²)*

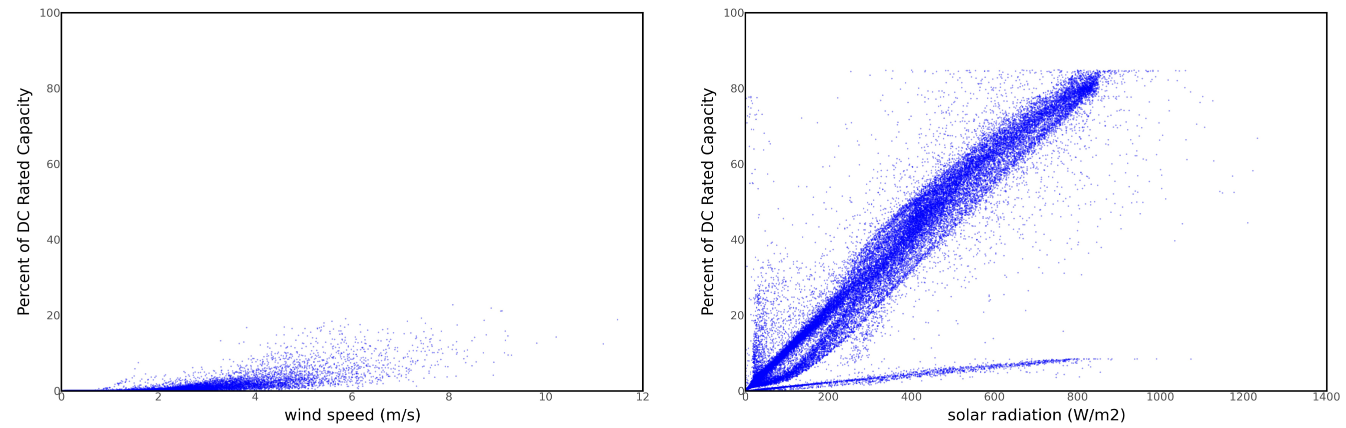

Figure 7 *Scatter plots showing the measured output of wind turbines (left) and photovoltaic panels (right) as a percent of their rated DC output vs. wind speed and global horizontal solar radiation, respectively.*

CONCLUSION

Through the development and implementation of the Crissy Field Center dashboard, we have described features of a monitoring and dashboard system for high performance buildings. First, the monitoring strategy needs to be focused on the aspects of performance defined in a project. For instance, we more fully measure comfort metrics by including both air as well as surface temperatures, but could improve by including sensors to measure mean radiant temperature specifically. Second, for most users, data needs to be represented primarily in multiple contexts, including temporal, spatial, and in relation to multiple variables. Lastly, the data needs to be systematically stored and easily available so that further analysis can be performed to investigate questions that arise while exploring data using the dashboard.

ACKNOWLEDGMENTS

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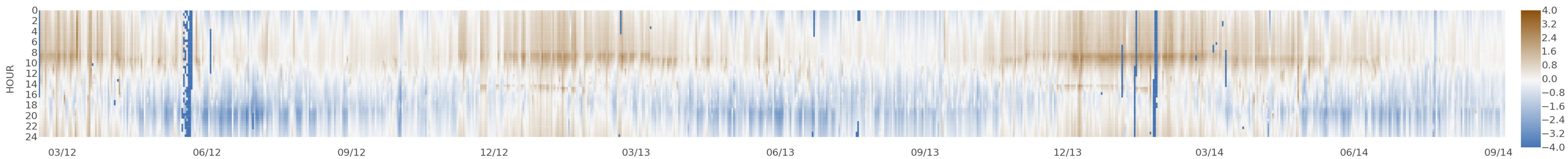

Figure 6 *Hourly graph studying the contribution of floor surface versus air temperature to operative temperature, over the entire monitoring period to date. (°C)*

Helping the design team better visualize energy and its interactions with the help of physically accurate graphical representations

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ABSTRACT

It is no secret that architects understand visual representation better than numerical formats. As climate engineering consultants on design teams, it is imperative that design concepts are conveyed in a way that improves the fundamental understanding of the energy concepts and their interactions with various aspects of design. This paper demonstrates through examples, the impact of enhanced graphical communication with the design team, how it results in a better understanding of the energy concepts by the architects, and the design implementation involving building users and operators.

INTRODUCTION

The involvement of climate engineering consultants is often misunderstood to be limited to the energy and daylighting analysis in the design phase. It is equally important for the consultants to ensure a holistic understanding and implementation of the energy design concepts right through building construction. It is imperative for the information exchange between design team members to be precise and devoid of any 'information noise'. Thoughtful and accurate graphical representation is a powerful tool in this kind of assistance. This paper broadly categorizes examples of graphical representation into three areas – context orientation, design influence and physical sensation of energy for building occupants. The impact of this awareness on user behavior is briefly demonstrated.

Multiple examples of enhanced visual representation from practice, such as energy and carbon benchmarking, climate analysis and its comparison with locations familiar to the design teams, various design strategies to effectively achieve the energy balance and incident solar radiation with related shading strategies based on different orientations and façade types are demonstrated in this study.

INTENT AND OBJECTIVES OF ENHANCED GRAPHICAL COMMUNICATION

The primary objective of the enhanced graphical communication in the context of construction industry is to provide accurate information in a concise manner targeted at a specific audience with an ability to be absorbed in an appropriate amount of time based on the design phase and decision making intent.

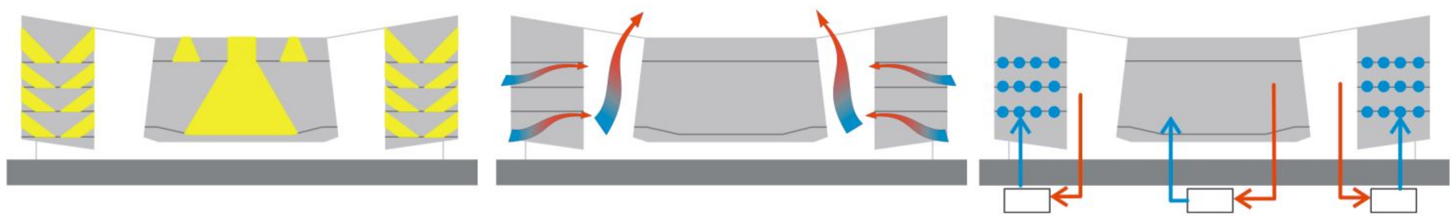


Figure 1 (a) Daylighting penetration in the space. (b) Natural ventilation concept. (c) Radiant heating/cooling concept.

For example, illustrating a climate concept for a competition project presents itself with a unique challenge - the information needs to be self-explanatory so that the judges will be able to decipher it in a matter of the few seconds available to them. In a contrasting example, for an end of phase design report - as a reader can afford to spend the required time to understand and absorb – visual communication needs to be able to deliver detailed information such as the fundamentals of a climate concept or basic physics behind the working of any specific component in the design. Figure 1(a through c) illustrates conceptual diagrams using schematic key sections of a building made for a design competition while Figure 2 shows key results of an exhaustive study involving complex design issues, operating modes and rigorous thermal simulation.

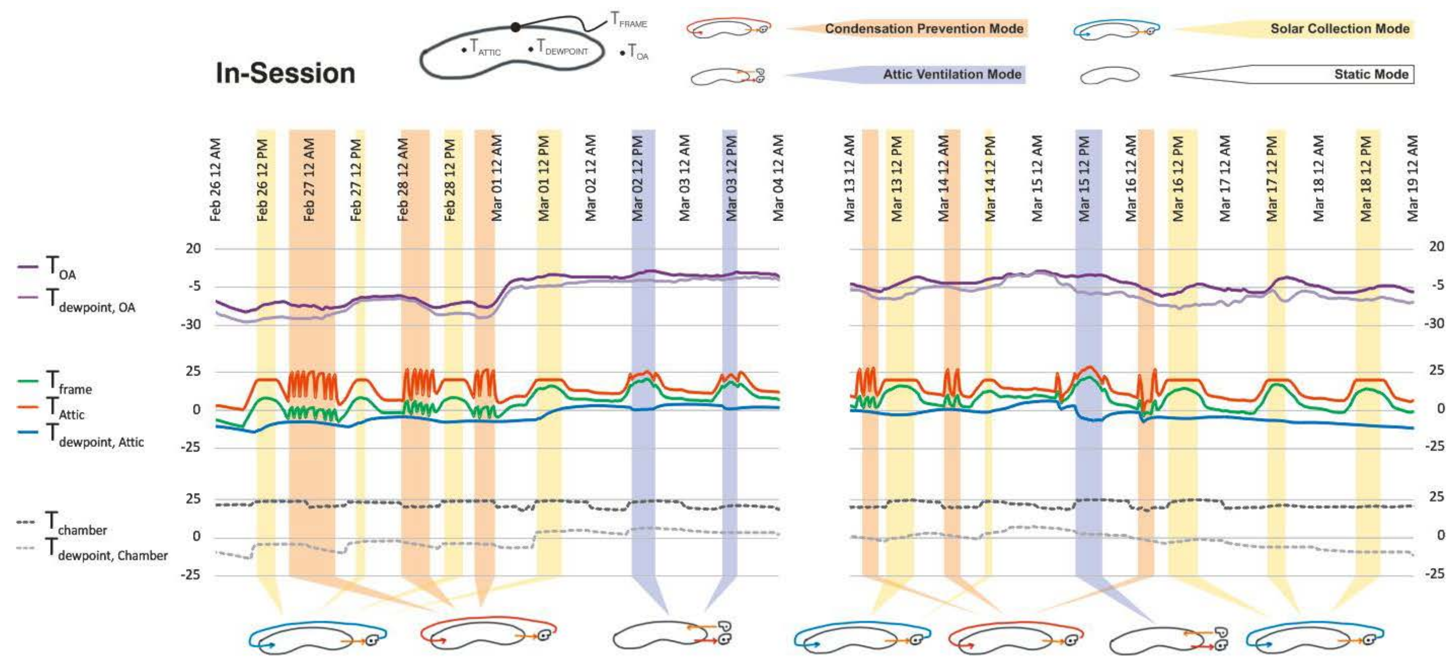


Figure 2 Hourly, daily and weekly variation in outdoor temperature/weather conditions and the corresponding switching between different mechanical operation modes.

PROCESS

In order for the 'integrated design process' to be successful and efficient, it is essential for every team member to accurately interpret information. One way to ensure that the graphical format is clear enough to be understood by a variety of collaborators is by getting inputs from colleagues who come from varying professional backgrounds such as engineering, architecture and liberal arts. For a design driven consulting firm, the toolbox includes design thinking for concept generation and integration, simulation models, custom software, tailored engineering analysis and physical experiments used to develop and validate new ideas. It is equally important then, to effectively communicate the products of this toolbox with rest of the design team for implementation in the actual buildings.

Context Orientation

Context orientation for the purpose of design communication means careful selection and demonstration of precedents and relevant facts related to a project or a study. The intent is to provide a framework for benchmarking and goal setting, highlight challenges and opportunities by filtering out irrelevant information and provide a clear direction for discussion and design thinking on the subject. Figure 3 shows the examples of energy and carbon benchmarking where instead of proposing only a target number, the project potential in relation to the current building stock is provided with an emphasis on 95 percentile and a very aggressive 'PassiveHaus'[1] standard – all in one graph. Heating, cooling and other electric loads are shown separately in the graph as different design strategies can influence each of these energy uses almost in isolation.

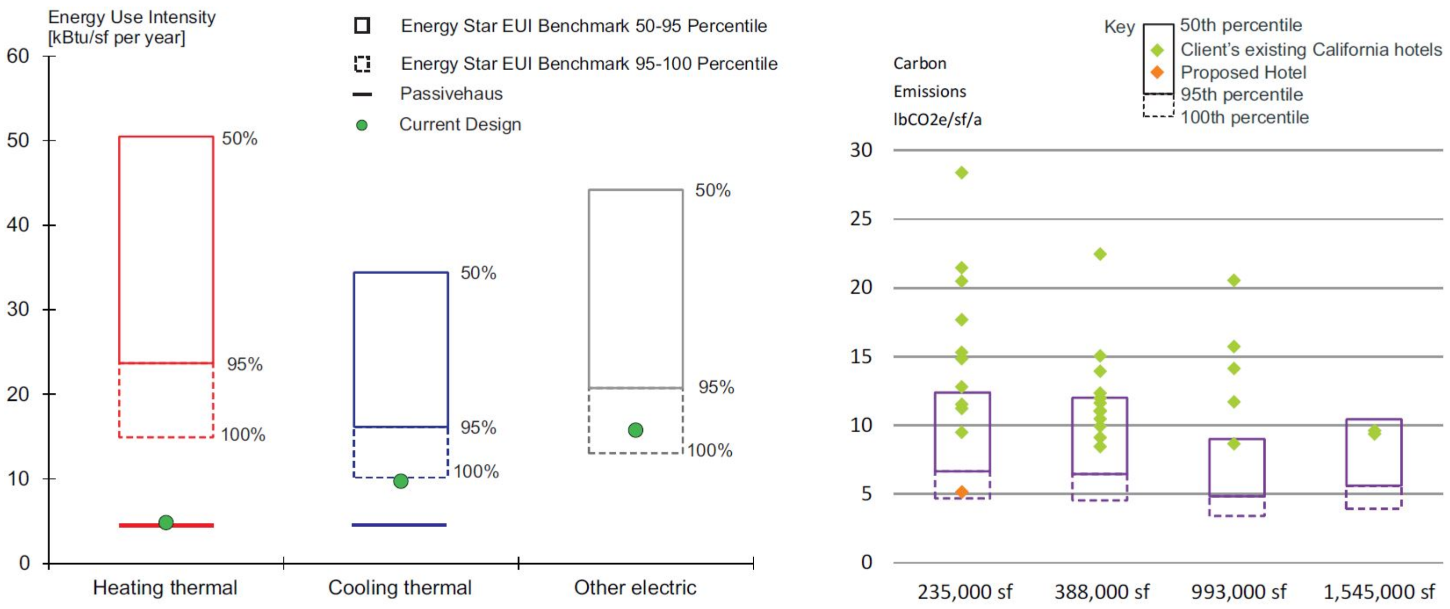


Figure 3 Energy and carbon benchmarking.

Design Influence

Continuous feedback between architects and consultants (with communication materials as simple as hand-drawn sketches to as complex as whole building drawings and energy/daylighting simulation results in Figure 2) is a sign of a truly integrated design process. Most of this communication is geared towards critical decision making. This process can be explained in three key steps: Understand the situation, Evaluate choices and Explain details.

Understand the Situation is about knowing the constraints or boundary conditions for a problem before seeking a solution. For example, the first step in the climate engineering process is to know the local climate for the project. Only after that is understood, can the concept development process begin. Figure 4 shows how this information is taken a step further by comparing climate data for the project location with that of the architect's location. This kind of information has been much appreciated by the architects as they have a 'feeling' for their local climate and find it easier to understand and visualize the climate for the project location due to the graphical comparison.

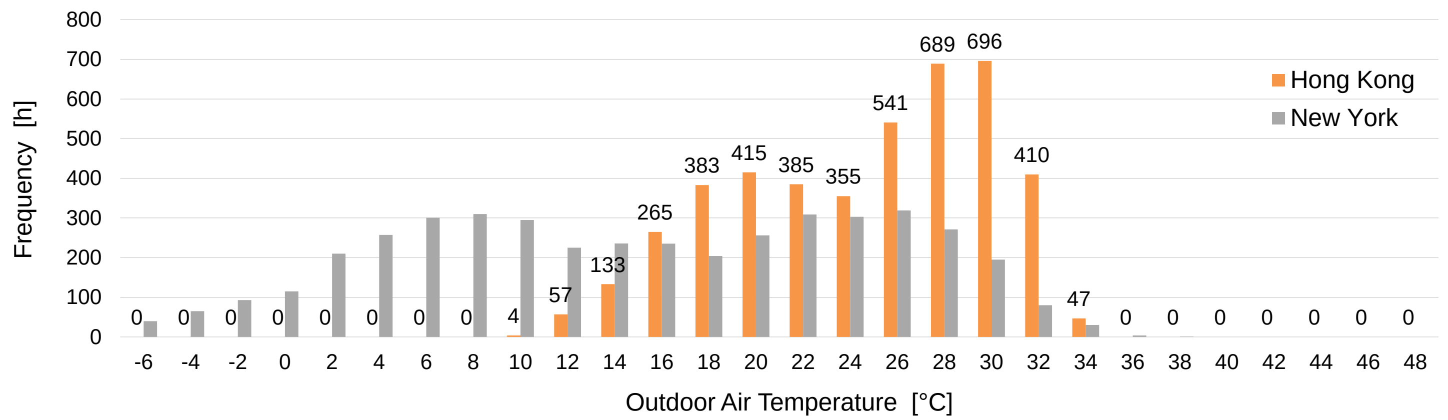


Figure 4 Temperature histogram of the architect's location and the project location.

Another example in Figure 5 demonstrates incident solar radiation data for a project with a continuous curving footprint resulting in various (highly glazed) facade orientations. For the purpose of simplification, all the orientations were approximated into a maximum of twelve. For easier data visualization, a wind-rose format was adopted. A shading projection factor was recommended for all simplified orientations in the same format. A mental comparison of 'solar-rose' with a 'plan view' helps better understand the shading requirements for respective orientations. The final design result was a continuous shading overhang varying in depth as per the orientation derived from this study.

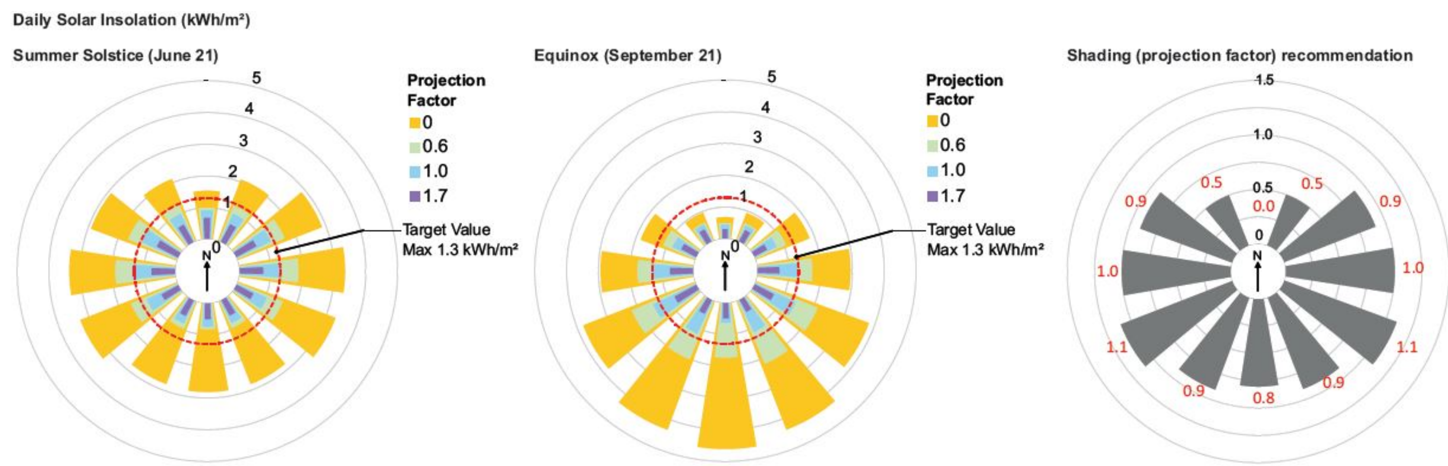
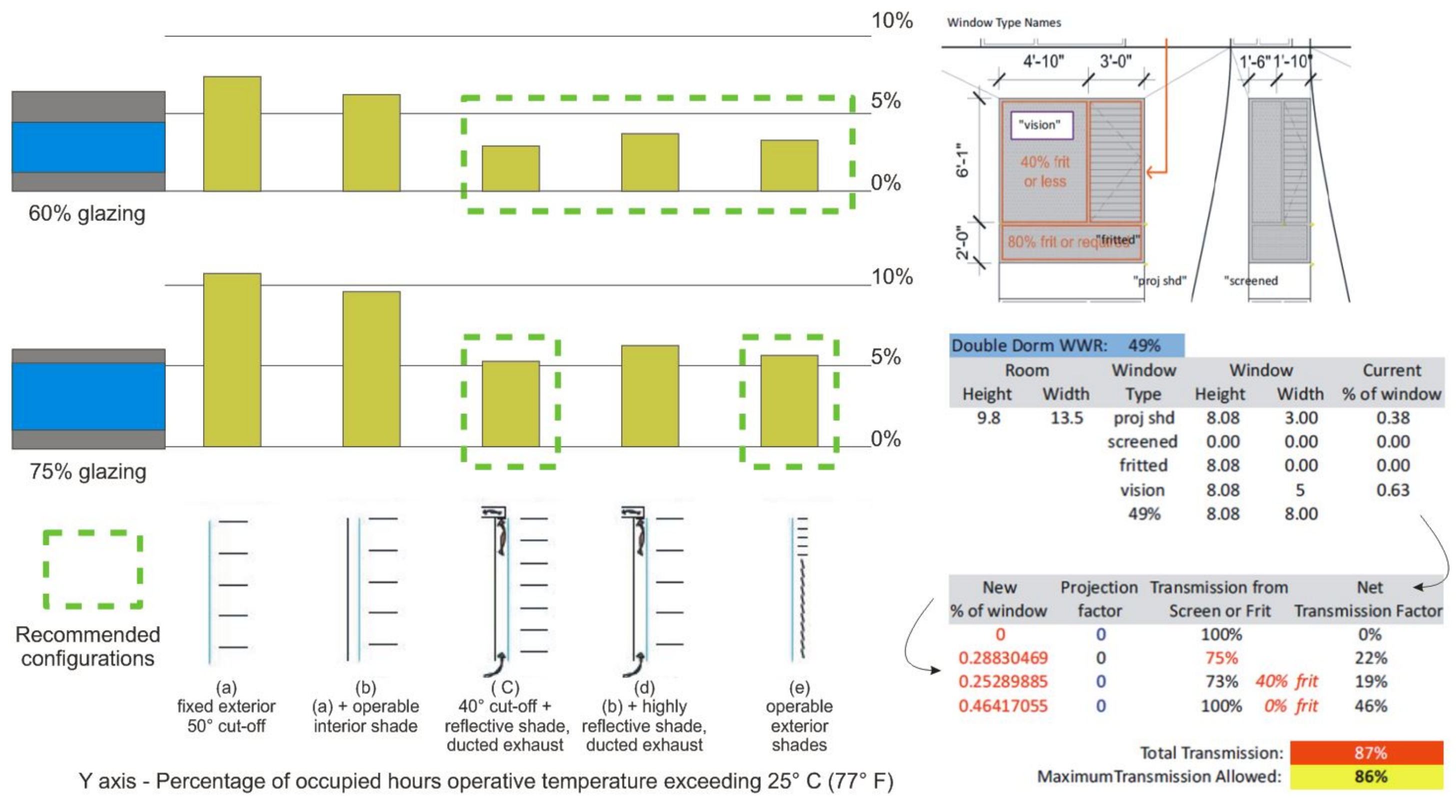


Figure 5 'Solar rose' – Solar radiation data mapped into a wind-rose format and shading projection factor recommendations.



(a) (b)

Figure 6 (a) Comparative comfort study for a 'commons space' façade. (b) Shading transmission calculation tool.

Evaluate choices. In most cases, there is no single 'correct' design solution for a problem but a range of solutions and the task before design teams is to select the desired solution from an available range, based on the given constraints. In the complex process that is building design, there are multiple interdependencies and an ideal decision making process should include consideration and representation of as many critical variables as possible. It is necessary then to present the data in a format which makes a consistent comparison. The critical aspect in this is to make the data visually comprehensible while keeping it scientifically accurate. The goal is to pave the way for exchange of ideas and decision-making based on thorough analysis. The final solution may depend on variables such as aesthetics, user preference, cost and more.

Figure 6(a) Demonstrates results for a comfort study related to a façade configuration for a commons space. Some of the decisions to be made are amount of glazing on the south façade, exterior shading and façade composition. By performing a comparative study with multiple variables, the decision making process is made easier and open.

Another valuable method of effective communication, especially with architects, is to offer a level of flexibility by creating simple and user friendly analysis tools instead of providing end results only. When empowered with an ability to test performance impact of design permutations and combinations in real time, it has helped develop intuition amongst architects. Figure 6(b) shows snapshots of a spreadsheet-based calculation tool which let the architects test different shading transmittances for glazing area on a dormitory room façade. The ability to get results in real-time offered the architects a high level of flexibility within a required framework. The back-end included a combination of results from TRNSYS[2] (Energy simulation software) and spreadsheet calculations. Another significant advantage turned out to be efficient use of time.

(a) (b) (c)

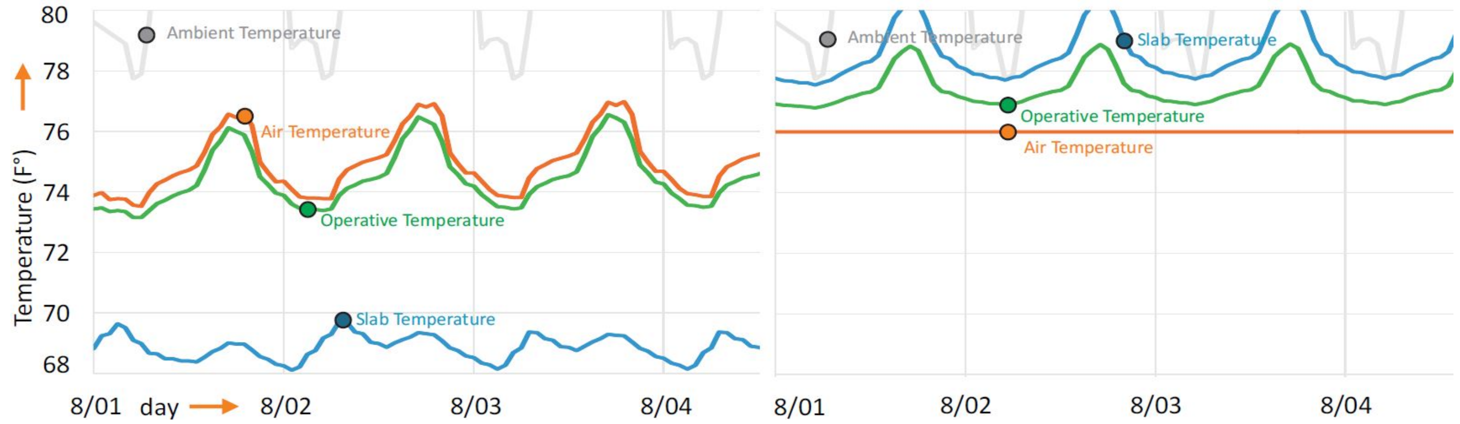
Figure 7 (a) Final shading design as a result of information in Figure5 (b) South façade of a built project as a result of information in Figure 6(a) (c) Rendering of a dormitory room window design as a result of information in Figure6(b)

Figure 7 shows the built projects or projects under construction – for which the design decisions were directly influenced by the studies demonstrated through the graphical representations in Figure5 and Figure6.

Explain Details. During or after the process of decision making, there is often a requirement to validate design concepts; if they work under a variety of boundary conditions and that there are no weak links. It is especially true in case of concepts or products which are unfamiliar to the design team or decision makers. Often a concept might be rejected not because it doesn't work but because the design team or the decision makers do not have a clear understanding of the concept or their concerns haven't been addressed. It is necessary then as a consultant to improve the understanding and instill a level of confidence about the concept with the help of detailed analysis and effective communication. Figure 8 demonstrates part of a detailed study elaborating the effect of various mechanical systems on operative temperature.

Physical Sensation

Physical sensation of energy refers to the experience of physical phenomena such as radiation (solar, radiant heating/cooling) or convection (ventilation) in a habitable space; allowing the building users to appreciate changes in the physical conditions through passive design strategies and by making the invisible, visible. An effective way to improve comfort conditions in the buildings is to provide individual control over the environment and encourage user participation in operation of the building. Providing visual cues to operate windows or to turn the lights off are some of the effective ways (Figure 9).



(a) (b)

Figure 8 Comparative comfort study between (a) Radiant system and (b) All air system with 58°F supply temperature.

(a) (b) (c) (d)

Figure 9 (a) Winter garden with operable shading. (b) Man-made cloud installation (c) & (d) Operable window indicators.

CONCLUSIONS

Effective graphical communication results in informed decision-making. From our experience on multiple projects at a global scale, the most valuable benefit of precise graphical representation has been the effective use of design team meetings. It means more time for meaningful collaboration and concept development, rather than analysis explanation. This process encourages understanding of range of options and relative influence of different factors, beyond a single fixed recommendation. Enhanced graphical representation backed by precision of engineering knowledge has resulted in an evolved dynamics of architect-consultant relationship - architects are more inclined to keep the consultant's engagement in a design-focused role rather than an analysis focused role - resulting in superior performance oriented and genuinely integrated architectural design.

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1. PassivHaus is an internationally recognized, performance-based energy standard in construction. (http://passiv.de/en/index.php)
2. TRNSYS is a complete and extensible simulation environment for the transient simulation of thermal systems including multi-zone buildings. (http://sel.me.wisc.edu/trnsys/features/features.html)
3. Figure 7(a) courtesy of Behnisch Architekten and ZAR
4. Figure 7(c) courtesy of Studio Gang and University of Chicago

The Study of Sky View Factor in Urban Morphologies: Computational Tools and Methods of Analysis

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ABSTRACT

Regarding density, many studies confirm that a crowded space cannot be described easily by one single number. Its perception differs from individual to individual, leading to the concept of perceived density. Among the aspects that can influence such perception, the sky view factor (svf) can be highlighted. This paper focuses on the sky view factor and investigates different methods to calculate such parameter in urban design. Several procedures and computational tools were listed and three of them were selected for practical investigation: I) MapInfo and II) Sky View Factor Calculator, both for the analysis of fish eye lens images; and III) DEM (Digital Elevation Model). Three neighbourhoods in Sao Paulo, Brazil, were chosen as case studies for investigation with the selected methods: Cambuci, Bela Vista and República. The results of the case studies and the application of each tool are discussed. As part of the results, unexpectedly lower values of svf were obtained with the DEM analysis in comparison with the fish eye lens methods. DEM allowed for a quick view of the distribution of svf in urban area; nevertheless, it showed lack of accuracy on the representation of irregular surfaces and other obstructions at the pedestrian level such as trees and urban equipment. The fish eye lens methods were more efficient for the analysis of smaller areas with more details; however, its results also depend on the procedure used to calculate the svf. Finally, it was concluded that the efficiency of each method of sky view factor prediction depends on the aim of the specific research; and that the svf is a valid parameter to inform sustainable urban design. Further investigation on the subject is recommended.

1. INTRODUCTION

Many studies confirm that density in urban spaces cannot be described only as a single number (quantity of individuals or buildings divided by area) (Churchman, 1999; Rapoport, 1978). The definition of what is a crowded place can vary from individual to individual, according to their culture, background, location and function. In urban morphologies, additionally to all these aspects, the sky view factor (svf) can be highlighted (Cheng, 2010).

Sky view factor indicates the percentage of visible sky for a specific observer, or, in other words, it indicates the openness of an area (Holmer, Postgard & Eriksson, 2000). The factor varies from 1 to 0, being 1 a completely unobstructed view of the sky and 0 an obstructed view. It is a dimensionless parameter related to two planes: horizontal and vertical. In analyses of urban morphologies, the svf is closely related to the streets' width and the height of obstructions (such as buildings, monuments, objects, trees).

The sky view factor has already shown its importance in solar availability and natural lighting studies. Many researches were developed to facilitate its identification and analysis through computational tools, mathematics, diagrams and graphics, fish eye lens images and image processing tools (Souza, Rodrigues & Mendes, 2003; Ratti & Richens, 2004; Zaksek, Ostir & Kokalj, 2011; Santos, Lima & Assis, 2003).

Aiming to test some of those methods, three case studies were developed in Sao Paulo, Brazil, as part of a major research on building typologies and urban morphology in the city. In the first case, Cambuci, new buildings were proposed and their orientation was analysed for a fixed population density. For the second and third neighbourhoods, Bela Vista and Republica, existing building typologies were studied.

2. COMPUTATIONAL TOOLS FOR SKY VIEW FACTOR ANALYSIS

Three methods involving computational tools were selected for practical investigation regarding the svf: I. DEM (digital elevation model) which was generated by Image J or NIH Image; II. MapInfo; and III. Analysis of fish eye lens images.

2.1. DEM (Digital Elevation Model)

According to Ratti & Richens (2004), DEM is a simplified way to represent urban morphologies. It is visualized in a grayscale plan where each colour determines the height of the pixel. In simple image software such as ImageJ and NIH Image (Ratti & Richens, 2004), it is possible to create a plan and apply different colours to each pixel. The same programs are capable of reading and translating those colours into their corresponding height, turning the 2D plan into a 3D model.

The DEM is an 8-bit .TIFF image in grayscale, with colours varying from 0 to 256. Each plan is created with a lock-up table (LUT) which is similar to a template. It allows the user to attribute a height to each colour. Normally, the grey number 0 is defined as 0m height, grey number 1 equals 1m height, and so on. This makes it easier to change the images’ height without recoloring the entire plan.

It is possible to import images into ImageJ and NIH Image, however, inevitably some colour fixing will be necessary. Both software are able to create macros which allow other types of analysis. Nonetheless, it is also possible to calculate built area through histograms, to create sections of the site and axonometric representations, as well as to visualize the 3D model.

There were found two macros for DEM analyses. The first one was developed by Ratti & Richens (2004) based on a study on building’s shadows. Their aim was to determine the sky view factor by the shadows created by the obstructions. This macro was written for NIH Image, which only runs on iOS system; due to this fact, and because the only system available for the present research was a Windows, it was adopted the second macro developed by Zaksek, Ostir & Kokalj (2011). The latter was developed in ENVI+IDL in a partnership between the Universities of Hamburgo (Germany) and Ljubljana (Slovenia) with the objective of identifying surfaces’ imperfections in geomorphological studies.

2.2 Fish Eye Lens Images

Fish eye lens allow a physical camera to register a field of view wider than regular lens, close to 180° wide. The resulting image is created in a complex process. Firstly, the obstructions (pedestrians, buildings, objects) are projected in a half-hemisphere, or sky vault, which defines the field of view around the lens. Then, such images are projected again in a horizontal plane (Souza, Rodrigues & Mendes, 2003). For the analysis of the first case study, Cambuci, as the model was already built in Google SketchUp, two digital cameras were adopted to generate the fish eye lens images: VRay for SketchUp and Autodesk Ecotect Analysis. For the latter tool, it was necessary to import the model from SketchUp and rebuild it. In the second and third cases studied (Bela Vista and República) the focus was the existing morphology, and thus images were shot with a physical camera.

Computational tools were then used to analyse the obtained images. Generally, such tools divide the sky vault into several parts which are later projected in the horizontal plane. Following, each part is identified as being and obstruction or a part of the sky. The software differ from each other by the way they divide the vault.

Two computational tools were adopted for this phase of the research. The first one was developed by Santos, Lima & Assis (2003) at the Universidade Federal de Minas Gerais and was analysed by MapInfo. The second one, Sky View Factor Calculator, was developed by Lindberg & Holmer (2010).

Other methods were listed; however, due to limitations on time and software availability, it was not possible to assess them all. Among those, it is worth mentioning Souza, Rodrigues & Mendes (2003), which developed a SIG based model created in ArcView. As part of such method, the sky view factor is calculated by an extension called 3DSkyView, which runs together with 3d Analyst, from ArcViewGIS. Once the observer is located, it is possible to generate stereographic and orthographic projections. The obstructions and the visible sky are automatically detected by the extension, which additionally compares the generated image with a stereographic grid of the sky vault, enabling the calculation of the sky view factor. The main reason for not including that method on the present study was the unavailability of a former version of ArcViewGIS, which is required for the 3DSkyView extension to run.

Another tool listed, although not adopted, was CityZoom, developed by SimLab from Universidade Federal do Rio Grande do Sul, in Brazil. This tool is intended for urban design applications (Ely, Lins & Sonza, 2009). As part of the main features, regarding the geometry to be studied, a 3D volume can be drawn directly in the software or a .DXF file can be imported from Autocad. The software can calculate sky view factor by itself without any extensions. It seems to be a fast and friendly tool, but unfortunately it was not available for download by the time this research was ongoing.

2.2.1. Fish Eye Lens Image and MapInfo

Following Santos, Lima & Assis (2003), a fish eye lens image of the area of interest is compared to a template: a grid divided in cells developed by Souza, Rodrigues & Mendes (2003). A number corresponding to a portion of the sky vault is attributed to each cell, as indicated in Fig. 1. The sum of numbers equals 10,000, representing 100% of the visible sky.

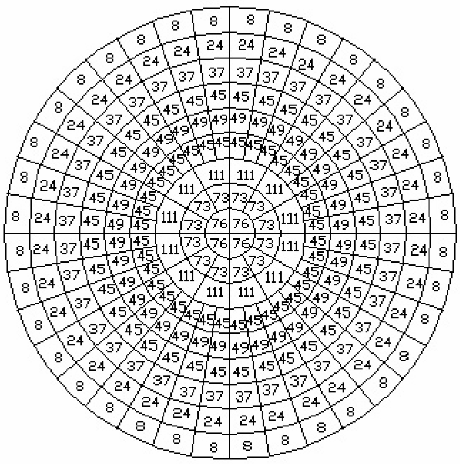

Figure 1. Grid for MapInfo analysis, developed by Souza, Rodrigues & Mendes (2003).

The grid was vectored in Autocad, as well as the fish eye lens image; in the latter case, the obstructed area was separated from the unobstructed one. Using MapInfo (Santos, Lima & Assis, 2003), it was possible to compare the fish eye lens image and the template, resulting in the sky view factor.

2.2.2. Sky View Factor Calculator (Lindberg & Holmer, 2010)

This computational tool was developed in MATLAB, and runs on MATLAB Compiler Runtime (MCR). It can analyse any image file and detect the portion of sky and obstruction automatically. This tool is easier and simpler than the method developed by Santos, Lima & Assis (2003). Once the fish eye lens image is uploaded, the program turns it into a black and white image, where black represents the obstructions and white, the visible sky. Subsequently, the tool can calculate the sky view factor according to two methods.

The first method (Johnson & Watson, 1984) analyses the wall view factor, which is the area occupied by the walls that contour the urban canyons. It was originally used for evaluation of long wave radiation exchange within urban canopies.

The second calculation method (Holmer, Postgard & Eriksson, 2000) analyses each pixel of the image and assigns, to each one, a value representing its percentage in the sky vault. Such portion is related to the angular distance from the centre of the vault. In the present study, the results obtained with this calculation method were discharged due to a great discrepancy in comparison with the results of the other methods.

3. CASE STUDIES: ANALYSIS OF THREE NEIGHBOURHOODS IN SAO PAULO

Sky view factor was predicted and analysed for three neighbourhoods in Sao Paulo: Cambuci, Bela Vista and República. All areas are located in the city centre, have mixed occupation (commercial and residential), urban infrastructure and demonstrate to have potential for an increase in population density.

3.1. Cambuci

The first neighbourhood analysed was Cambuci. A target density was adopted and 16m x 50m buildings were proposed and located in a chosen plot with a minimum distance of 25m between them, according to solar access criteria. For this first essay, the existing buildings, trees and street furniture were discarded. Three scenarios were created and analysed with DEM and fish eye lens images processed with MapInfo method.

For the DEM analysis, the macro was calibrated for a 350 and 250 radius and 180 directions. Each pixel represents 1m distance (Fig. 2).

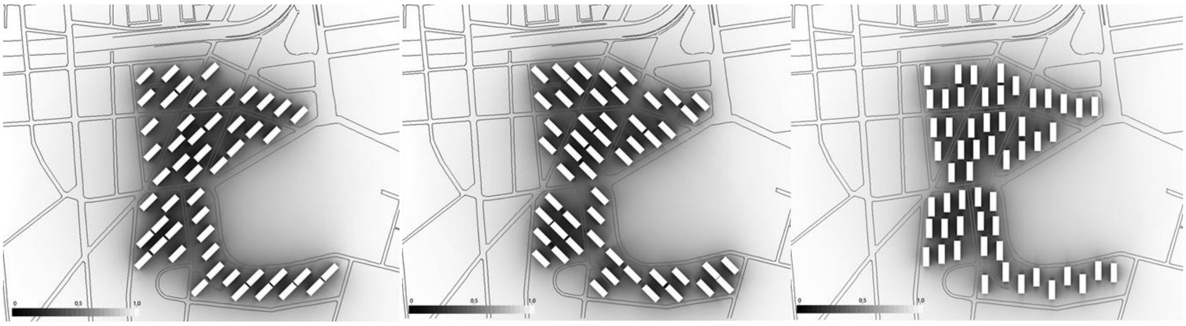

Figure 2. Cambuci neighbourhood, scenarios 1 to 3 analysed with DEM (radius=350 / 180 directions).

Since the scenarios were created in Google SketchUp, firstly fish eye lens images were generated by VRay for SketchUp and by Autodesk Ecotect for comparison between the two results, and latter the images were analysed with MapInfo.

Figure 3. Cambuci neighbourhood: scenarios 1 to 3 with their points of analysis.

Four points located in the centre of each street around the plot were selected for evaluation (Fig. 3). The results of sky view factor can be seen in Table 1.

Table 1. Sky View Factor Analysis for Scenarios 1 to 3 in Cambuci

Scenarios	Point of analysis	VRAY Image + MapInfo	Ecotect Image + MapInfo	DEM (radius:350/ directions:180)	DEM (radius:250/ directions:180)
Scenario 1	1	0.35	0.32	0.22	0.28
	2	0.41	0.29	0.20	0,23
	3	0.34	0.32	0.21	0.29
	4	0.34	0.25	0.22	0.26
Scenario 2	1	0.42	0.34	0.25	0.28
	2	0.33	0.27	0.22	0.23
	3	0.29	0.20	0.18	0.29
	4	0.32	0.30	0.22	0.26
Scenario 3	1	0.34	0.29	0.24	0.28
	2	0.21	0.24	0.21	0.23
	3	0.18	0.25	0.17	0.29
	4	0.20	0.28	0.20	0.26

It is possible to see that, in general, the VRAY image indicated more visible sky than the DEM analyses. However, such lens is more esthetical than technical, and no precise information was found about the type of image generated by this plugin. The results of the fish eye lens images varied from 0.02 to 0.12 in comparison with the DEM evaluation. Despite the different radius adopted for the DEM analysis, the svf results showed some consistency between them and were very similar to the ones obtained with Ecotect + MapInfo.

3.2. Bela Vista

Aiming to study the existing urban morphology, the second neighbourhood analysed was Bela Vista. A block was selected for the investigation and its buildings were catalogued. Fish eye lens pictures were taken directly on site with a camera. Ten points of analysis were selected, comprising all corners of the block and the centre of each surrounding street (Fig. 4). Due to the existence of many trees in the area, it was not possible to determine the svf with the MapInfo method. For this case, it was adopted the Sky View Factor Calculator (Lindberg & Holmer, 2010).

In order to compare results, a DEM was developed for the area (Fig. 5). Since the fish eye lens pictures were taken in pedestrian level (2m from the ground), to build the DEM, the height of the buildings were reduced in 2m. Additionally, the topography in Bela Vista is uneven, and thus its surface was reproduced considering 10cm for each pixel, aiming to improve precision. As a limitation, it was not possible to reproduce trees and other street furniture which are required to accurately represent the area.

Figure 4. Points of analysis in Bela Vista with fish eye lens pictures.

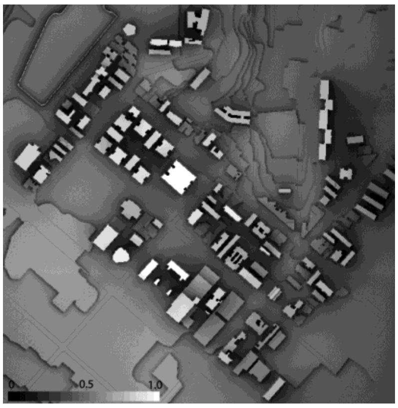

Figure 5. DEM for Bela Vista, at pedestrian level (configuration: radius 380 and 180 directions).

Table 2. Sky View Factor Analysis for Bela Vista.

Point of analysis	Fish Eye Len Pictures + Sky View Factor Calculator	DEM at pedestrian level (radius:380/ directions:180)
1	0.52	0.46
2	0.37	0.43
3	0.22	0.40
4	0.45	0.45
5	0.30	0.33
6	0.47	0.42
7	0.37	0.31
8	0.42	0.41
9	0.50	0.38
10	0.25	0.32

Regarding the fact that the DEM did not consider the obstruction caused by trees, it was expected to present higher svf results than the ones from the fish eye lens images (Table 2). Nevertheless, some of the results were similar (see points 4, 5 and 8) and can be justified by: I. The difficulty to calibrate the Sky View Factor Calculator for the representation of the transparency of the trees; II. The lack of precision in DEM, as the 3D model was generated by a city plan provided by the City Hall website; and III. The difficulty to precisely identify in DEM the same points analysed with the fish eye lens.

3.3. República

The method of analysis adopted for the República neighbourhood is similar to the one adopted in Bela Vista. An urban block was selected and eight points of analysis were chosen (Fig. 5). The buildings were catalogued and fish eye lens pictures were taken in loco at pedestrian level with a physical camera. Those pictures were analysed with Sky View Factor Calculator (Lindberg & Holmer, 2010).

Figure 6. Points of analysis in República neighbourhood.

The urban surface in República is more even than the one in Bela Vista, thus the terrain did not need to be reproduced. A DEM at pedestrian level was also generated for that caseand compared to the fish eye lens pictures (Fig. 5 and Table 3).

Figure 7. DEM for República at pedestrian level (configuration: radius 220, 180 directions).

Table 3. Sky View Factor Analysis for República.

Point of analysis	Fish Eye Len Pictures + Sky View Factor Calculator	DEM at pedestrian level (radius:380/ directions:180)
1	0.36	0.26
2	0.30	0.17
3	0.33	0.34
4	0.24	0.23
5	0.26	0.23
6	0.24	0.20
7	0.41	0.30
8	0.16	0.14

Once again, there was a considerable difference between the results obtained by fish eye lens pictures + Sky View Factor Calculator method and DEM. One should expect DEM to show higher levels of visible sky than the former method, since it does not consider street furniture and vegetation, although this theory proved not to be true in both neighbourhoods.

4. CONCLUSION

During the development of this study, the fish eye lens pictures and the Ecotect lens showed sfv with more visible sky than the DEM method. It was unexpected due to the fact that DEM ignores vegetation and street furniture as obstructions, and therefore higher results of svf were expected.

Despite the differences among the results, one advantage of the DEM method for svf analysis is the possibility to obtain a general view of an urban area in opposition to a punctual analysis.

Regarding the results of this research, by analysing the existing morphologies in Bela Vista and República, the average sky view factors were:

- Bela Vista: 0.39
- República: 0.25

Thus, based on the perceived density concept (CHENG, 2010), the República neighbourhood can be said to be perceived by its users as a denser area than Bela Vista. Such result was already expected and it is probably due to the fact that the buildings in the first neighbourhood are placed directly on the front part of the lot, aligned with the street and close to each other. On the other hand, the buildings in the second neighbourhood are placed in the middle of the plot and most of them have gardens in the front part. The streets in Bela Vista were also wider and had plenty of trees, which according to Cheng (2010), helps reducing the perceived density.

Regarding this research, the method used to analyse sky view factor in areas with considerable amount of trees needs to be improved.

In the Cambuci area, the average sky view factor was:

- Scenarios 1 to 3, fish eye lens image from VRay: 0.30
- Scenarios 1 to 3, fish eye lens image from Ecotect: 0.28

- Scenarios 1 to 3, DEM analysis: 0.21

For that neighbourhood, the DEM method showed the lower results. However, for this specific research, related to the analysis of the perceived density, a simplification is suitable and thus the results could be considered as similar, leading to the conclusion that the perceived density in that area is higher than in Bela Vista, but lower than the density perceived in República.

Regarding limitations of the study, glare occurred in the fish eye lens pictures taken with physical camera in Bela Vista and República, which led the software to consider some parts of buildings and trees as part of the sky. The same issue occurred in the buildings covered by glass façades, which reflected solar radiation. *How does this fact effectively affect the perception of density?*

Some unsolved questions remain for a future research, such as the reasons why there were differences between the results obtained in the different methods and aspects of the DEM calibration. Another important issue is the search for methods to analyse the sky view factor in areas covered with vegetation. It was not possible to include trees in the DEM analysis, and the fish eye lens study demonstrated lack of precision.

The sky view factor is a parameter that influences many analyses, such as acoustics, thermic, ventilation and solar radiation (Cheng, 2010). For this reason, it can be emphasised the relevance of understanding the theoretical concepts and relationships among the variables involved in the subject of svf in order to analyse it with more precisely, combining both hypothetical models and existing areas which present multiple types of obstruction.

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Investigation of methodologies for artificial lighting performance simulations with the presence of shading devices in residential buildings

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ABSTRACT

In tropical countries, such as Brazil, daylight is an important feature used to reduce energy consumption in buildings. However its indiscriminate use may result in situations such as glare and excessive heating of the room. To prevent such unwanted situations and allow natural light in the room, shading devices appear as an important strategy. The Brazilian Regulation for Energy Efficiency of Residential Buildings (RTQ-R) considers shading devices by their effect on the thermal behavior of buildings, not taking into account the artificial lighting energy consumption caused by their presence. In order to study this issue, a thermo energetic behavior investigation was conducted for rooms with different shading devices. Simulations were performed in Daysim and EnergyPlus to get quantitative data about artificial lighting activation and the room´s energy consumption and thermal performance. This article shows the choosing process between the artificial lighting activation systems available in Daysim 3.1, to determine the best one to evaluate artificial lighting activation in residential rooms with shading devices. The studied systems are "switch off occupancy sensor" and "combination on/off occupancy and dimming system" which were named in this study "user-sensor" and "automatic-sensor", respectively. The automatic-sensor is controlled only by occupancy and illuminance sensors while the user-sensor is activated by the user. The results showed that, although the user-sensor demonstrates a situation closer to a real user, the automated-sensor allows a more accurate view of the need of artificial lighting activation. This was evidenced by the greater variance between the increase in energy consumption of rooms with shading devices, in comparison with the model without solar shading, for the automatic-sensor in regard to the user-sensor.

INTRODUCTION

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After years of intense and indiscriminate use of energy by man crisis were generated due to resources scarcity. An exemple is the 1970's oil crisis which affected the world economy and draw attention for other sources of energy. In Brazil, the 2001 energy crisis caused energy rationing and affected the country's economy and culture of consumption (BRASIL, 2012). As an important measure

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for energy efficiency, Brazilian government launched in 2009 the Regulation for Energy Efficiency of Commercial, Services and Public Buildings (RTQ-C) and in 2010 the one for Residential Buildings, the RTQ-R (BRASIL, 2010; BRASIL, 2012). These regulations stipulate references for the building's energy performance based on comparative methods and values to classify it as most efficient (level A) or less efficient (level E).

This recent interest in energy efficiency and environmental quality and comfort in buildings has stimulated a return to the use of natural light (ROAF, 2009). Besides the availability during great part of the day, the excellent color rendering index and the possibility of high illuminance levels in the room, natural lighting may be used to reduce energy consumption (CORBELLA E YANNAS, 2003). However, its indiscriminate admission in hot weather buildings may result in unpleasant situations such as glare and excessive heating. These situations lead to immediate solutions which block natural lighting (BOGO, 2009). In this context, shading devices are an important feature to avoid these uncomfortable situations and allow natural lighting integration to the room. However, they need to be designed considering the room's thermal comfort and natural lighting availability.

The importance of using shading devices for thermal comfort improvement has been demonstrated in recent researches such as Sorgato, Versage and Lamberts one (2011). They run computer simulations for a bedroom with shutter and another one without them in a residential building, for four different solar orientations and for the Brazilian Bioclimatic Zone 3 and Zone 8[1]. The results showed that for north and south façades the bedroom without shutters had an average of 32% more degree-hours summation than the bedroom with shutters. For west and east façades the average increase was 82% and 47%, respectively.

A study by Didoné and Bittencourt (2008) on the impact caused by the absence and the use of shading devices in the energy consumption of hotels adopted existing buildings which were not suitable for the investigated climate. The results showed that shading devices blocked the direct radiation and achieved an air conditioning energy saving from 2% to 6%. Besides, this change on the building façade promoted an efficiency natural lighting performance inside the rooms.

Cintra (2011) investigated the influence of the room depth on its daylight autonomy, for openings with and without shading devices. The study was performed through computer simulation in the software Daysim 3.1, for residential buildings, four solar orientations and 11 Brazilian cities. The author concluded that, for the conditions of her study, the maximum depth for a room without shading devices should be 2,6 times the window height, while for a room with shading devices this value should be 2,1 max, i.e., a reduction of 17,9%. Therefore, the presence of shading devices reduces the daylight autonomy of rooms.

In the RTQ-R the presence of shading devices in openings is defined by the *somb* variable and considered in the building envelope evaluation. *Somb* score ranges from 0 (zero) to 1 (one), being 0 for openings without shading devices and 1 only when used shutters (BRAZIL, 2012). Other shading devices, such as *brise soleil*, overhangs and balconies are scored based on two other methods and may receive up to 0.5 points. Thus, shading devices other than shutters cannot reach the maximum score, even though they can perform effective shading during daytime. This happens because the RTQ-R considers shading devices only by their effect in the room's thermal behavior, not considering the darkening of the room caused by their use.

In this context, Soares (2014) developed a study which aimed to improve shading devices evaluation in the RTQ-R. This study is part of a major project from CIE-BRASIL which intends to improve natural lighting issues in energy efficiency regulations in Brazil. Soares (2014) investigated the influence of different shading devices on thermal, luminic and energetic performance of residential rooms, considering Brazilian climate context, through computer simulations. In order to define the influence of shading devices on the room's natural lighting performance, computer simulations were

[1] The geographic limits of Brazilian Bioclimatic Zones (ZB) were delimited according to the bioclimatic strategies recommended for each point on the map of Brazil, based on Givoni Bioclimatic Chart and Mohoney Table criteria. The points with similar strategies were grouped in the same Zone, resulting in a total of eight Bioclimatic Zone, being ZB1 the coldest and ZB8 the hottest.

performed in the software Daysim 3.1.

In this software, user behavior in what concerns artificial lighting and blinds activation is defined by the Lightswitch algorithm. This algorithm was published by Reinhart (2004) and developed based on user behavior observations through field research in private and two-person offices. Based on these observations and in probabilistic analyses, Reinhart defined six artificial lighting activation models, which vary according to the activation (manually or automatically controlled) and the operation mode (on/off or dimmed). Therefore, a deeper investigation about these different Daysim 3.1 artificil lighting models was needed to determine which one would be the best fit for the CIE research. This article presents a discussion about the choosing process of the artificial lighting model to be used for the simulations for Soares' study (2014) about the impact of using shading devices in residential buildings.

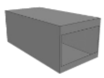
METHODS

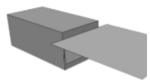
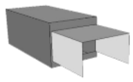
This study was developed in four steps. First, the artificial lighting activation models to be simulated were chosen. Then, the rooms were defined and at last, the lighting and energy consumption simulations were pereformed.

The system on/off was the most commonly found in residential buildings, therefore this kind of system was sought among Daysim 3.1 possibilities. It was needed special attention in this part as the Daysim artificial lighting models were idealized based on field researches in offices. First, the Daysim models were divided in two groups: the ones manually controlled and the ones automatically controlled. Then, a system from each group was chosen to be analyzed by simulation, according to their main characteristics. Finally, the simulations were performed in order to determine which activation mode, manual or automatic, and which Daysim model would be the best one to verify the artificial lighting activation necessity in residential rooms with shading devices.

The models defined by Soares (2014) were used for the simulations and are described as follows. The simulated rooms were the living room and the bedroom of an intermediate apartment of a condo building. They were tested for four solar orientations (north, south, east and west) and for the city of Florianópolis, representative of the Bioclimatic Zone 3 and classified as Cfa climate by *Köpper-Geiger*. A constant occupation was required to evaluate the shading devices performance in what concerns direct insolation control and daylight availability. The artificial lighting system was determined by a luminotecnic project. The opening area was defined according to the standard set by Guedes (2012) as recurring in residential buildings (15% of the floor area for the bedroom and 25% of the floor area for the living room). At last, different shading devices were selected to be compared to the ones referenced in RTQ-R, as showed in Table 1.

Table 1. Shading devices

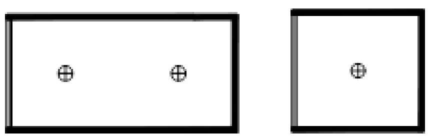
Model	Typology	Description
	No shading device (SP)	Model without shading device (score 0 in RTQ-R), basis for comparison of shading devices performance
	Shutters defined by RTQ-R model (VRTQR)	Shutters defined according to RTQ-R model: always closed for ZB 6 to 8 and closed during spring/summer and opened during autumn/winter for ZB 1 to 4
	Shutters with full opening (V90)	Operable window with two shutters and two glass panes. The full opening of the shutters allows 100% of natural lighting area
	Shutters with opening up to 45% of the total area	Sliding window with one fixed shutter pane, one movable shutter pane and one glass pane. Therefore, the opening for lighting is reduced to 45% of the total opening area

	Shading device defined by the latitud method, described in RTQ-R	Model based on RTQ-R latitude method. It is a simplified method for measuring overhangs, balconies or brise soleil shading
	Shading device defined by RTQ-R Annex 1 method (TN)	Shading device sized according to RTQ-R Annex 1 method
	Shading device which shades during the useful daylight availability period – Whole plate (PTI)	Model defined to shade the room during the useful daylight availability period (Guedes 2012[2]): from 7h40 to 16h20. Composed with one horizontal plate and up to two vertical plates
	Shading device which shades during the useful daylight availability period – Divided plates (PTF)	Model defined as the above, but with divided plates. It intends to investigate the influence of the shading device shape on the thermal performance of the room and the impact of more reflective surfaces in the luminic performance of the room

After defining the models the simulations were performed in Daysim. This software produces a report with metric values for each point of the sensors mesh previously defined. For this study it was used Daylight Autonomy metric to verify when the artificial lighting would be activated, based on the minimum illuminance level demanded by Brazilian regulation NBR 5413 (ABNT, 2013) – 100 lux for both living room and bedroom. The sensor mesh was located together with the lamps in order to verify weather they would be on or off. Therefore, for the bedroom it was used only one sensor, located in the center of the room and 75 centimeters above the floor, while for the living room there were two sensor located in the longitudinal central axis, at the same height (Figure 1).

The V90 and V45 shutters schedule was defined by Daysim dynamic shading model, which predicts that blinds will be lowered when there is excessive glare on the workplane or when direct solar radiation is above $50W/m^2$. The sensors used for this purpose were located together with the artificial lighting sensors. For the RTQ-R shutter (VRTQR) the schedule was defined seasonally, as exposed in Table 1. The static shading devices were drawn as part of the building, within the 3D model. The artificial lighting and shutters activation schedules were used as input data in EnergyPlus to get energy consumption results.

Figure 1. Location of sensors



ANALYSIS AND DISCUSSION

Selection of the systems for simulation

Based on Reinhart study (2004) concerning the comparison of artificial lighting energy consumption between different types of users and activation modes, the main characteristics of each Daysim 3.1 Lightswitch activation models were identified. This is presented in Table 2.

[2] Guedes (2012) defined the useful daylight availability period according to RTQ-R requirement which demands proof of a minimum illuminance level of 100 lux in a room for 70% of a year's daytime. The author considered an average daytime period from 6 AM to 6 PM and selected 70% of this time resulting in the period from 7h45 AM to 16h15.

Table 2 – Daysim 3.1 artificial lighting activation models

Models	Description
Manual on/off near the door	Typical on/off switch system near the door. The user activates the system once a day, when the illuminance level is insufficient. The system remains on for the rest of the occupation hours and the user turns the system off when leaving the office
Switch off occupancy sensor	The system is activated by the user, as the manual system above, but it is turned off automatically by an occupancy sensor
Switch on/off occupancy sensor	Automated model. The system is turned on and off automatically by an occupancy sensor
Photosensor controlled dimming system	The system is activated as in the manual model, but it is dimmed. Therefore, it complements the natural lighting illuminance. However, this model foresees that sometimes the user forget to turn off the system. It happens because is considered that depending on the natural lighting intensity the user might not see that the artificial lighting system is on when leaving the office so the system stays on during the night
Combination switch off occupancy and dimming sensor	Considers an initial manual activation by the user (switch) when one arrives at the office, but with a dimming activation by photosensor. The system is turned off automatically by an occupancy sensor. Therefore, the system is available only when the switch is on
Combination on/off occupancy and dimming system	Automated model which turns the system on and off by an occupancy sensor, but with a dimming activation by photosensor. Therefore, the system is available during the whole time the office is occupied

Later, the activating models were divided in two groups: the systems manually controlled and the ones automatically controlled (Table 2). One system from each group was chosen to be conducted to simulations, aiming to identify which type of control would be the most adequate for the investigation about shading devices impact on the room's lighting.

For the manually controlled group, the **manual on/off near the door** model is activated according to the user's behavior, which, many times, does not take into account the illuminance level. Therefore, it is not indicated for the proposed simulation.

Table 3 – System control modes

Activation mode	System
Manually controlled systems	Manual on/off near the door
	Switch off occupancy sensor
	Photosensor controlled dimming system
	Combination switch off occupancy and dimming system
Automatically controlled systems	Switch on/off occupancy sensor
	Combination switch on/off occupancy and dimming system

The **photosensor controlled dimming system** is not adequate for the proposal because considers an eventual user forgetfulness, as showed in Table 2. Therefore, this activating model does not allow an accurate investigation of the artificial lighting activation. The **combination switch off occupancy and dimming system** was dismissed because even though it considers that the user activates the system by a switch, the lighting is turned on by dimmer. Therefore, it does not represent an on/off system, as highlighted before as the object of study. Thus, the **switch off occupancy sensor** was chosen to represents the manually controlled group, being called in this article user-sensor. This activation model takes into account user behavior and an on/off model.

For the automatically controlled systems, the **switch on/off occupancy sensor** was dismissed because it is activated only according to the occupation, not taking into account the room’s illuminance level. Therefore, the **combination switch on/off occupancy and dimming system** was chosen for the automatically controlled group. In this article, it was denominated automated-sensor. Although this model has a dimming reactor, it was chosen once considers the illuminance level, while the other model considers only occupation. The automated-sensor has automation by photosensor and by occupation, i.e., artificial lighting is activated only when the room is occupied and illuminance level is lower than the pre-determined.

In order to approximate this activation mode to the residential buildings reality, it was estimated on/off activation based on the dimming system results. Thus when the dimming system presented any indicative of activation it was considered the complete activation of the system (100%).

Shading devices sizing

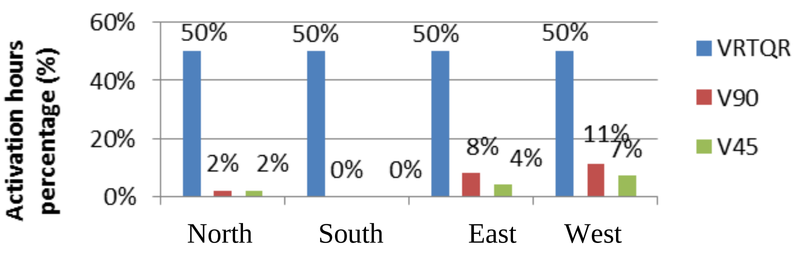
Table 3 shows the sizing of *brise soleil* type shading devices. In general, PTI/PTF was the larger device, followed by TN model. The model L23 was the smallest device.

Tabela 3 – Sizing of shading devices (*brise soleil* type)

	North			South			East			West		
	PTF/PTI	L23	TN	PTF/PTI	L23	TN	PTF/PTI	L23	TN	PTF/PTI	L23	TN
α	59.9°	51.1°	-	16.1°	51.1°	-	78.7°	45.0°	-	78.7°	45.0°	75.0°
βd	44.1°	-	-	9.2°	-	-	-	-	-	-	-	-
βe	44.1°	-	-	9.2°	-	-	-	-	-	-	-	-
γd	-	45.0°	-	-	45.0°	-	15.8°	51.1°	-	72.8°	23.5°	30.0°
γe	-	45.0°	-	-	45.0°	-	72.8°	51.1°	-	15.8°	23.5°	30.0°

Figure 3 shows shutters sizing, represented by the percentage of activation hours in relation to the room’s occupancy hours. It can be noticed that the device with the most activation hours is VRTQR. The other shutters, V90 and V45, presented few activation hours. These results can be explained by the sensor positioning. The shutter sensors were located in the same place as the lighting sensors; therefore it was far from the opening, so the sensor was little affected by direct insolation and excessive glare.

Figure 3 – Shutters sizing



Simulations results

Table 4 shows the activation hours percentage and energy consumption variation for each shading device and activation mode, for the north oriented façade. The other façades had the same caracteristics. The graphics below are a compilation of living room and bedroom results.

Observing the shading devices performance it can be noticed that larger devices, as PTI, PTF and VRTQR, cause greater darkening of the room and, consequently, more artificial lighting activation hours. V45 showed great activation hours because it has a fixed shutter pane which contributes to a greater darkening of the room. Also according to Table 4, it can be noticed that user-sensor caused more activation hours and energy consumption than automated-sensor. However the raise in energy consumption when used different shading devices, when compared to the model without shading devices, was not always higher for the user-sensor. This can be seen in Table 5.

Table 4 – Comparison between energy consumption and artificial lighting activation for user-sensor and automated-sensor for north oriented opening

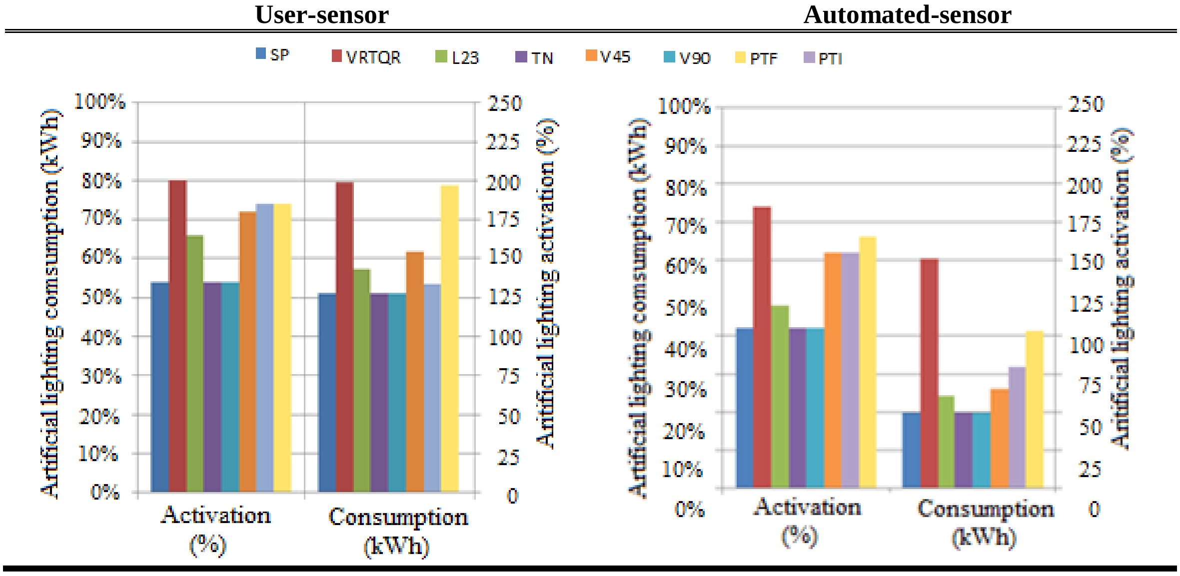
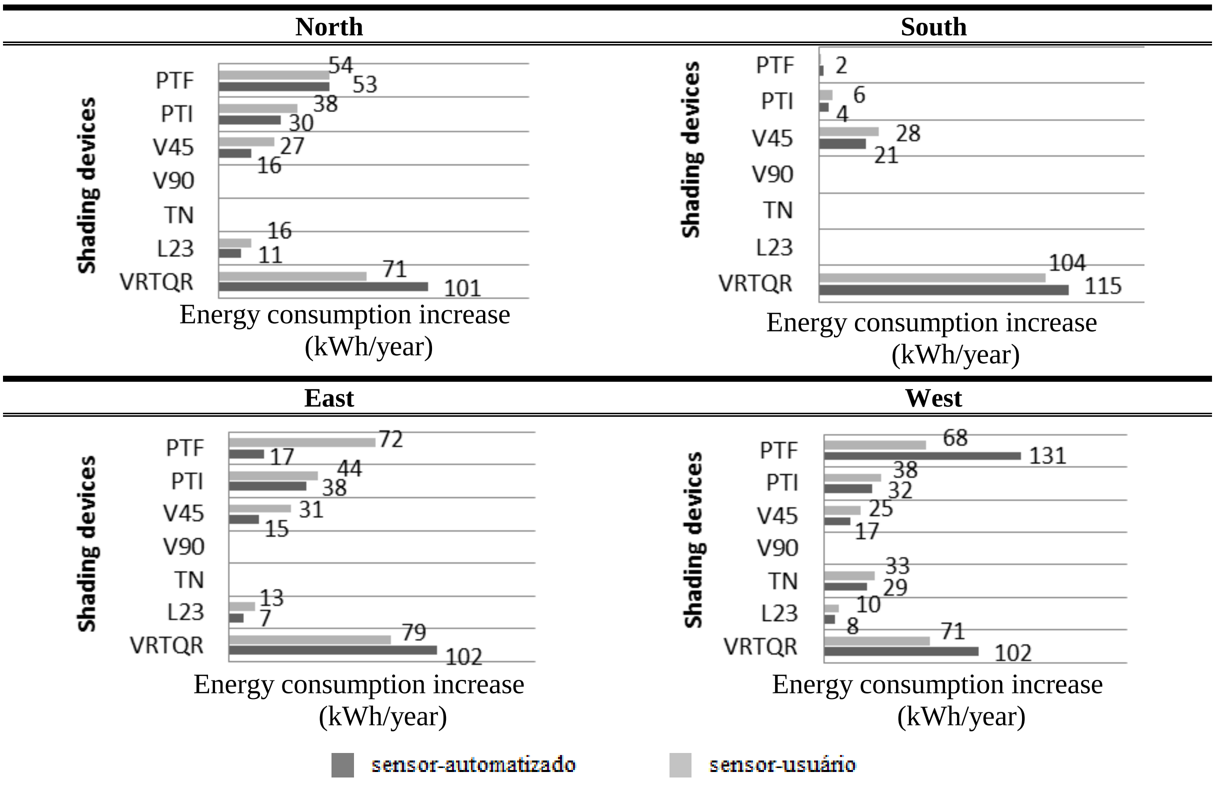


Table 5 – Comparison between user-sensor and automatic-sensor on the raise in energy consumption for the models with shading devices when compared to the model without any device



Besides that, it can be noticed a smaller variation in energy consumption raise for the different shading devices when the artificial lighting is activated by the user-sensor than when it is activated by the automated-sensor.

CONCLUSIONS AND FINAL CONSIDERATIONS

In this study two artificial lighting activation modes were investigated and compared in what concerns energy consumption performance: manually controlled systems (user-sensor) and automatically controlled systems (automated-sensor). Based on the systems analyses it was concluded that the automated-sensor represents an idealized user who activates artificial lighting only when necessary to complements natural lighting illuminance, while the user-sensor is closely to a real user behavior.

The results showed that the user-sensor consumes more energy than the automated model. However, when comparing the energy consumption raise when used different shading devices in relation to the base model (without shading device), for each activation model, it was noticed that there was a larger variation for the automated-sensor than for the user-sensor. This can be explained by the fact that the automated-sensor has a variable activation during the day, due to the photosensor. This irregularity in activation results in a higher energy consumption than the user-sensor, as it is needed more energy to activate the artificial lighting system than to maintain it on. In addition, the user role in the user-sensor model tends to reduce shading devices influence on the room's lighting, as the user makes artificial lighting activation more homogeneous, turning the artificial lighting on even when is not necessary.

Therefore, the automated-sensor was chosen to be used on the shading devices lighting performance analyses, once this activation mode allows a more accurate view of the need of artificial lighting activation. It is understood that this article meet the goal of understanding how Daysim 3.1 artificial lighting activation models work and also showed the influence of this choice on the simulation results.

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Session 8A : Material technology

PLEA2014: Day 3, Thursday, December 18, 2014
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Possible Application of Seaweed as Building Material in the Modern Seaweed House on Læsø

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ABSTRACT

The aim of the paper is to present the possible application of seaweed in the contemporary environmentally friendly and affordable architecture. Properly used, seaweed can be an ultimate sustainable material, which is not only available in many areas of the word, but also reproduces itself in the sea and is very easy to gain on the seashore. In some regions, where the quantity of building materials is limited (e.g. Danish islands), seaweed was traditionally used in vernacular architecture. Today, when many countries are threatened with deforestation, we are looking for cheap materials alternative to wood. Seaweed has some important advantages: it is non-toxic and fireproof, provides good insulation, reduces CO_2 emission, has a life expectancy of more than 150 years and, what is also valuable, can be visually attractive. To the top of that, using seaweed can promote the respect for the uniqueness of regional architecture. Some examples of creative and contemporary dwellings made of seaweed as well as the brand new construction methods are presented and discussed in purpose to assess the promising possibilities of rediscovering this forgotten material.

Keywords: vernacular architecture, zero emission, building conservation, low energy materials

INTRODUCTION: ORGANIC MATERIALS IN VERNACULAR ARCHITECTURE.

Gaining building materials from the environment has been one of the most natural architectural concepts from the beginnings of humanity. As pointed by Torben Dahl “Throughout the world, the expressions of traditional architecture are based on and adapted to local conditions. This applies primarily to the local availability of materials and the response to the climatic conditions” (Dahl, 2008, p.8). Locally available, organic or non-organic substance, could be found not only in low-tech constructions but also in very advanced projects, based on the most contemporary technologies. In both cases such material choices increase the connection with local culture, create harmonious composition with the landscape and help reducing transportation. Organic materials deriving from the same climate zone are also well adapted to the climatic conditions.

In vernacular architecture natural materials were used almost exclusively. Today many architects combine them with concrete and steel to achieve modern appearance. In some cases the reason for abstention from the use of natural materials is the awareness of the threat of over-exploitation of the environment. For example the usage of wood needs to be carefully considered to avoid cutting valuable tree species and to maintain a balance of wooded areas, both on the local and the global scale. In some other circumstances the construction system, the functional requirements or even the artistic vision may entail the specific materials, not necessarily natural. Still, it is worth to remember that organic elements of the building also can have a contemporary appearance. Amazing wealth of materials found in nature endows architecture with the unique character. While timber and stone are highlighted in many projects, there is a lot of interesting but almost totally unknown (or forgotten) materials, that may be applied in modern, ecological and affordable architecture. One of such promising examples is seaweed.

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SEAWEED CLADDING TRADITION

Nowadays the usage of seaweed in the building industry is observed in very few places in the world. However, it is worth to note that properly used seaweed can be an ultimate sustainable material, which is not only available in many regions, but also, as Jørgen Søndermark noticed "reproduces itself every year in the sea, (…) comes ashore without any effort from humans, and it is dried on nearby fields by sun and wind" (Søndermark, 2013). As a building material it seems to have a great potential since it provides good insulation (which is typical for mineral materials), it is non-toxic and fireproof, and it has a life expectancy of more than 150 years.

In some coastal areas, where the quantity of timber (or even straw) was limited (e.g. on small Danish islands like Læsø), while a lot of seaweed was thrown out by the sea, the eelgrass was used in vernacular architecture, mainly for the house cladding. According to Realdania Byg, the non-profit organization who initiated a preservation project “Seaweed Houses on Læsø”, there were hundreds of seaweed cladded houses on the island. Unfortunately today there are only 36 of such homes left.

Figure 1 The Kaline’s House (dated 1865) on Læsø with traditionally thatched seaweed roof, restored in 2012 by Realdania Byg. Photographer: Helene Hoeyer Mikkelsen/Realdania Byg (2012).

PRESERVATION PROJECT ON LÆSØ

In the continuation of efforts for preserving the cultural heritage of the small region of Læsø, in 2012 Realdania Byg organized the restoration of 150-year-old Kaline’s House on Læsø, with traditionally thatched seaweed roof. Simultaneously the same group launched the architectural competition with a goal to design the modern house on Læsø, referring to the local tradition but offering the contemporary standard. The Vandkunsten architectural studio, who won the competition, developed a very creative and contemporary dwelling made of seaweed. As a consequence the Modern Seaweed House on Læsø was built in 2012-2013, according to the project of Vandkunsten studio in cooperation with Realdania Byg. The designers decided to use the seaweed as a traditional material but they also proposed the new technology and the brand new construction method.

In vernacular structures the seaweed was placed directly on the roof, one layer after another, to provide the demanded thermal insulation and impermeability. Within years new layers were added and some roofs became very thick, they would even reach the thickness of 1,5 meter. The drawback of that system was not only the size, but also the weight of the roof, with the increased risk of collapsing. Although some of the houses could be perceived as beautiful from outside, the visual comfort of the user was often disturbed by small windows, additionally shaded by many layers of seaweed, that would block the sunlight penetration into the living areas of the house as shown in **Figure 1**.

THE CONTEMPORARY DWELLING MADE OF SEAWEED

The authors of the Modern Seaweed House on Læsø carried out Environment Behavior Studies (EBS) in purpose to use vernacular architecture as a model, as suggested by Rapoport, and consequently to improve the solutions observed in vernacular buildings instead of copying it directly (Rapoport, 2006). To provide the functional and comfortable dwelling the architects focused on the value of natural light and space. They developed the summer holiday residence with a big common space in the center and some smaller rooms on both sides of the building. The house is heated with a highly efficient heat pump, placed in an adjacent shed that can also be used as a storage (e.g. for bikes and kayaks). The building is tight, well insulated and fitted with an effective mechanical ventilation system with heat recovery. Due to the proper insulation it is possible to maintain constant temperature of minimum 10˚C throughout the winter, so that the house is frost-free.

Figure 2 The Modern Seaweed House (2012-2013) on Læsø, designed by Vandkunsten in cooperation with Realdania Byg. Photographer: Helene Hoeyer Mikkelsen/Realdania Byg (July 2013).

The light construction was designed without steel nor concrete. Instead, to emphasize the unique spirit of the island, the sea plant from the family Zostera marina was used as a building material i.e. as an insulation for ceilings, roofs and walls. As shown in **Figure 2**, in some elements it was introduced in the clearly visible form, while in others it is slightly hidden, both for functional and esthetic reasons.

The most obvious application of seaweed was the roof cladding shown in **Figure 3a**. Nevertheless, it was necessary to propose the brand new technology to achieve the lightweight and contemporary looking roof. On the other hand it was equally important not to lose the ambience of simplicity, connection with the environment and the obvious utilitarism, that stood behind the usage of the natural material that could be found on the beach. Therefore the seaweed was stuffed into the nets knitted from a woolen yarn as shown in **Figure 3b**. Each element is 6-8 meters long and closed at both ends. These nets were attached to the façade and to the roof, where they formed the original and expressive finishing. At the same time, the seaweed filling was placed inside the wooden cassettes made of low processed timber and divided into smaller inner sections. These prefabricated building modules formed the house framework and provided an excellent insulation of floors, walls and ceilings with the λ value 0,0376 W/mK (Pedersen, Ransby 2005, p.4). Another innovative application of seaweed was inspired by traditional mattresses. The dried seaweed was used for internal finishing elements, which are stuffed with eelgrass and covered with natural colored linen so that they slightly resemble the mattresses as shown in **Figure 4a**. These elements were used for internal wall cladding. The bright linen corresponds well to the timber color and gives the interiors light and natural appearance as shown in **Figure 4b**. Furthermore such used seaweed has exceptionally good acoustic properties.

Another seaweed feature, which is very useful in building, is the ability to absorb and give off moisture. That contributes to the regulation of indoor air humidity parameters. Various solutions, based on the seaweed application, created truly comfortable interiors with high-quality indoor microclimate. The list of possible variants of seaweed implementation can be developed further, in purpose to expand

a) b)

Figure 3 (a) The seaweed roof cladding and (b) the detail of seaweed placed in the knitted nets. The Modern Seaweed House (2012-2013) on Læsø, designed by Vandkunsten in cooperation with Realdania Byg. Photographer: Helene Hoeyer Mikkelsen/Realdania Byg (July 2013)

a) b)

Figure 4 (a) Dried seaweed inside white linen finishing elements and (b) natural bright interiors. The interiors of the Modern Seaweed House (2012-2013) on Læsø, designed by Vandkunsten in cooperation with Realdania Byg. Photographer: Helene Hoeyer Mikkelsen/Realdania Byg (July 2013).

the prospective options for affordable sustainable building. The Modern Seaweed House has a very low energy consumption and due to the fact that the organic materials were used almost exclusively, the house accumulates more CO_2 than it was emitted within the whole process of production and transportation of the building materials (Realdania Byg, Walther, 2013).

THE LIFE CYCLE ASSESSEMENT FOR THE MODERN SEAWEED HOUSE ON LÆSØ

In purpose to assess the potential for the application of seaweed as a sustainable material for the contemporary, ecological and affordable architecture the Life Cycle Assessment (LCA) was carried out by Kauschen (Kauschen, 2013).

In general LCA is a technique that allows to assess the environmental aspects and potential impacts associated with products and processes by:

1. Compiling relevant energy and material inputs and environmental releases
2. Evaluating potential environmental impacts connected with identified inputs and releases
3. Interpreting the results for making more conscious decisions (EPA, 2006, p.2).

LCA method evaluates all stages of product's life and includes all phases necessary to produce, operate and dispose a building ("cradle to grave"). The phases are divided into raw material acquisition, building materials and/or component production, use and maintenance, waste management ("End-of-Life"). The applied "End-of-Life" method includes also the possibility of recycling. In accordance to ISO14040 standard, the research involved:

1. Goal and Scope defining (at this stage the assessment context was established, the boundaries and potential environmental effects were identified, a functional unit as a reference value for the assessment was defined);
2. Life Cycle Inventory (LCI, i.e. the inventory analysis which identifies and quantifies energy, water and materials usage and environmental releases) with the model based on building description, drawings and data extraction from BIModel (Revit).
3. Life Cycle Impact Assessment (LCIA) that allows to assess the potential ecological effects and refers to all inputs and outputs defined in the inventory analysis.
4. Interpretation of the inventory analysis and impact assessment in purpose to select the products and processes "with a clear understanding of the uncertainty and the assumptions used to generate the results" (EPA, 2006, p.2). In this stage the results were interpreted and validated.

The categories and calculation methods used in LCIA match DGNB standard (DGNB, 2010), as a DGNB Denmark (Danish adaptation of German standard DGNB, Deutsche Gesellschaft für Nachhaltiges Bauen), is a standard certification system for sustainable building in Denmark (Green Building Council Denmark, 2012). The impact categories and characterization factors are based on CML 2001 method, developed by the University of Leiden (Guinée, 2002). The environmental data was taken from ökobau.dat database (2011). For new processes (already not existing in ökobaut.dat), the assumptions were based on similar processes from Ecoinvent database (2.2), information from experts and producers Environmental Product Declarations (EPD). The Excel tool developed for the calculation of the product system was based on the method described in DGNB manual (DNGB, 2010). It should be mentioned that this LCA was carried out to identify potential environmental impacts with a goal to optimize the project in these terms and no critical review was undertaken. Thus the assessment can be classified as the life cycle screening (hot-spot analysis) instead a full LCA according to ISO standard 14040. The following impact categories of the seaweed building were analyzed: global warming potential (GWP100) [kg eq. CO_2], ozone depletion potential (ODP) [kg eq. R11], photochemical ozone creation potential (POCP) [kg eq. C_2H_4], acidification potential (AP) [kg eq. SO_2], eutrophication potential (EP) [kg eq. PO_4], non-renewable primary energy demand (NPED) [MJ], renewable primary energy demand (RPED) [MJ], total primary energy demand (TPED) [MJ], water usage [t], waste production [t], hazardous waste production [t], abiotic resource depletion [t], excavation residues [t]. For the LCA calculations the functional equivalent of a holiday property was set at $86m^2$ gross floor area, $30m^2$ loft and $124m^2$ terrace. The house has up to 10 beds and is used 168 hours a week, whole year, for

50 years (Kauschen, 2013, p.7). The building includes about 200 components and 38 different materials, which are divided into different building elements shown in **Table 1 and 2**. Electric air-water heat pump is used for heating and hot water preparation. The BE10-calculation shows a total energy requirement of 64,4kWh/m^{2}a, while the total electrical energy need is 54,4kWh/m^{2}a. BE10 is the software developed by the Danish Building Research Center (SBI), mandatory to be used in Denmark for energy calculations for reference purposes.

Table 1. Compiled Results of LCA, part 1. Based on Kauschen (Kauschen 2013).

Category [unit] / Building element	weight [kg]	GWP global warming potential [kg CO_2 eq]	ODP ozone depletion potential [kg R11 eq]	POCP photochemical ozone creation potential [kg Ethen eq]	AP acidification potential [kg $SO_{2\ eq}$]	EP eutrophication potential [kg Phosphat eq]
Façade	15681,27	-2820,77	0,00	1,27	19,09	-30,23
Roof	21729,36	-1295,54	8,64E-05	2,11	31,63	-84,48
Structure	9328,74	-2012,86	2,38E-05	0,24	3,23	-5,97
Interior	9223,66	-1480,38	9,06E-06	0,96	11,49	-3,54
Bathroom	2066,92	813,81	3,72E-06	0,24	1,55	0,17
Exterior	7817,99	-2023,87	1,52E-05	0,17	3,42	0,56
Electric & Heating Equip.	429,00	124109,06	5,52E-04	18,28	231,94	32,53

Table 2. Compiled Results of LCA, part 2. Based on Kauschen (Kauschen 2013).

Category [unit] / Building element	NPED non-renewable primary energy demand [MJ]	RPED renewable primary energy demand [MJ]	TPED total primary energy demand [MJ]	Water water usage [t]	Waste waste product. [t]	Hazardous waste hazardous waste product. [t]	Excav. residues excavation residues [t]	Abiotic res. depl. abiotic resource depletion [t]
Façade	-11009,1	247945,06	236900,16	-3760,8	-1,4	0,03	-5,45	0,00
Roof	26106,34	345462,56	371552,79	3054,4	-1,66	0,09	1,8	0,02
Structure	-18287,4	102619,32	84783,86	-1811,33	-3,55	-2,08E-04	0,99	-0,01
Interior	-6050,89	138832,69	132725,43	-1319,91	-1,05	2,62E-03	4,31	-3,45E-04
Bathroom	12162,18	398,85	12801,75	375,41	-2,14	1,28E-04	3,93	0,01
Exterior	-22732,2	90248,8	67516,62	-223,64	-2,79	-1,37E-03	-2,13	-0,01
Electric & Heating eq.	14898856,95	587595,04	2077369,87	311588,36	2,43	4,29E-04	237,91	0,01

To check the environmental impact of the holiday house three energy scenarios were proposed: without operational energy; operating with energy from DK wind power; operating with energy from DK Grid Mix **(Tables 3,4,5)**. The option to use wind power was the most interesting since there is no need to produce renewable energy in the holiday house itself. Solar energy was not taken into account as the house is situated in the shadow of the forest and also because the photovoltaic panels would not fit to the concept of the seaweed roof that should preserve the unique spirit and heritage of the place.

Table 3. Environmental Impact. Based on Kauschen (Kauschen 2013, p.14)

	Category of influences	GWP	ODP	POCP	AP	EP
	Unit	kg eq. CO_2	kg eq. R11	kg eq. C_2H_4 (ethene)	kg eq. SO_2	kg eq. PO_4 (phosphate)
Scenario 1 without operational energy	Total /50 years	-8.830,61	0,00014	4,93	70,59	-116,96
	Per m^2/year	-2,00	3,18E-08	0,00112	0,01600	0,02651
Scenario 2 energy from DK wind power	Total/ 50 years	-5.827,05	0,00066	5,92	79,35	-116,12
	Per m^2/year	-1,32	1,51E-07	0,00134	0,01799	-0,02632
Scenario 3 energy from DK Grid Mix	Total/50 years	115.278,45	0,00069	23,21	302,54	-84,43
	Per m^2/year	26,13	1,57E-07	0,00526	0,06858	-0,01914

Table 4. Energy Resources. Based on Kauschen (Kauschen 2013, p.14)

	Category of influences	**NPED** non-renewable primary energy demand	**RDEP** renewable primary energy demand	**TPED** total primary energy demand	TPED/share of RPED
	Unit	MJ	MJ	MJ	%
Scenario 1 without operational energy	Total/50 years	-24.255,84	913.136,76	889.013,38	100
	Per m^2/year	-5,50	206,99	201,52	100
Scenario 2 energy from DK wind power	Total/50 years	24.537,32	3.045.474,74	3.070.062,41	99,2
	Per m^2/year	5,56	690,35	695,92	99,2
Scenario 3 energy from DK Grid Mix	Total/50 years	1.465.601,11	1.500.731,80	2.966.383,25	50,6
	Per m^2/year	332,22	340,19	672,42	50,6

Table 5. Other Selected Resources (Inputs And Outputs). Based on Kauschen (Kauschen 2013, p. 14)

	Category of influences	Water usage	Waste	Hazardous waste	Excavation residues	Abiotic resource depletion
	Unit	T	t	T	t	t
Scenario 1 without operational energy	Total/50 years	-6.098,20	-11,81	0,12	0,34	0,01
	Per m^2/year	-1,38	-0,00268	2,77E-05	0,00008	3,01E-06
Scenario 2 energy from DK wind power	Total/50 years	-2.658,51	-11,50	0,12	16,84	0,02
	Per m^2/year	-0,60	-0,00261	2,78E-05	0,00382	5,43E-06
Scenario 3 energy from DK Grid Mix	Total/50 years	305.490,16	-9,39	0,12	238,24	0,02
	Per m^2/year	69,24	-0,00213	2,78E-05	0,05400	5,42E-06

CONCLUSION

The LCA analysis of the Modern Seaweed House on Læsø proved that with the proper insulation and the usage of wind energy the building has negative carbon footprint and minimal potential environmental impact throughout the assumed lifetime of 50 years. The conservative approach to the data selection for calculations was chosen, especially regarding the End-of-Life scenarios. Such conservativeness reduced the risk of obtaining too favorable assessment which could lead to the erroneous interpretation. In most impact categories the outcome is determined by the type of energy supply. The presented results of calculations carried out for scenarios 2 and 3 show the impact of the choice of the energy source on the environmental performance of the building. In the majority of cases DK wind power energy scenario allows to achieve much better results in comparison with DK Grid Mix energy scenario. The values achieved in scenario 1 proved a very low level of the environmental impact of seaweed used as the building material in the Modern Seaweed House on Læsø.

Due to the continuous emission of CO_2 to the atmosphere, the amount of seaweed in the seas and oceans is actually increasing. That should put our attention on this plant as a potential building material and a source of energy, especially today, when many countries are threatened with deforestation and we are looking for cheap materials alternative to wood. The important advantages of seaweed should be widely recognized: it provides good insulation, great acoustics, humidity control, visual comfort and the reduction of CO_2 emission. It is also non-toxic, fireproof, low-energetic, biodegradable with a life expectancy of more than 150 years. The seaweed is covered with the sea salt and thus naturally protected against bacteria or insects that could destroy the structure. However, it is important to note that seaweed is such a good material choice when it is harvested naturally, i.e. collected on the beach, dried on the meadows (not in ovens) and transported on short distances only. Used that way seaweed can promote the respect for the uniqueness of regional architecture but simultaneously can be easily adapted to the specific local conditions, including different cultural and climatic factors. This is in accordance with the statement of Peter Sørensen and Winnie Friis Møller that “Architecture is a connecting link between place, climate and human life” (Sørensen, Møller, 2008, p.13).

Finally, what is also valuable, seaweed can be visually attractive and its usage allows to establish the balance between the traditional and modern architecture. The preservation initiative of Realdania Byg helped to involve local community into the process which increased the awareness both of the natural and cultural heritage of the island. Consequently that leads to the protection of the architecture of the past and at the same time to the development of the sustainable architecture of the future.

ACKNOWLEDGMENTS

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DESIGN BEST PRACTICE METHODS TO MINIMIZE THE IMPACT OF BUILDING MATERIALS ON URBAN MICROCLIMATE

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ABSTRACT

Urban spaces in tropical country like India have always been the focus of socio cultural activities. In recent times these activities are stressed by increased urbanization. Among many factors that influence outdoor ambient temperature (traffic, pollution, population density…) the building surface treatments have also contributed in challenging the urban micro climate. Insufficient open spaces, diminished wind movement and strong irradiation from the high rise densely packed built environment has very much reduced the quality of urban outdoor life. Though there are many individual studies on the built form and building material influence on urban micro climate, they seldom give comprehensive guidance to the city designers, essentially the planners and the individual architects.

This paper investigates the influence of building materials on the micro climate of urban commercial streets (pedestrian users) by comparing their thermal performances. The study also tries to explore possible design interventions to minimize the impact of the building materials on the urban micro climate. Henceforth the outcomes will create cognizance among the designers to evolve climate sensitive design and material choice. Urban Micro Climate - Building Materials - Design Solution. The inferences in this paper will enable the architects and planners to design buildings with the understanding of their response to the urban microclimate and comfort of the pedestrian users.

KEY WORDS Urban Microclimate, Building Materials, Heat Transfer, and VASARI

INTRODUCTION

The phenomenon of city - induced environmental change has been known for many centuries. The ancient Indian Architectural manual “Silpa Sastra”(translated by Acharya 1979) laid out rules for the siting of villages, towns and forts based on prevailing wind directions and solar orientation.(Rohinton Emmanuel,2005). The city design is basically composed of many elements like the buildings, open spaces, networks (roads, streets, pathways, and bridges), traffic (vehicle & pedestrians), and vegetation. The inter relationship among these elements influence the quality of the urban environment. Though there are many factors that define the quality of urban life (environmental, functional, and aesthetic) this paper focuses on the environmental quality of the cities.

A large number of road users in India are pedestrians. (Gururaj G,2006)(Peden M, Scurfield R, Sleet D, Mohan D, Hyder AA, Jarawan E, et al.).The environmental comfort of the pedestrian users is seldom given a thought by the planners, developers and designers. The factors that influence the outdoor thermal comfort of the pedestrian users can be broadly classified as the **Climatic Factors** (Solar Radiation, cloud cover, precipitation, wind speeds, Humidity, and air temperature) and the **Physical Factors** like (orientation, Aspect Ratio, Vegetation, Sky View Factor (SVF), Building Materials) (Oke et al., 1987 and Santamouris, 2001). The influence of the building materials on the urban microclimate focusing on to the pedestrian users and the possible solution is a part that still needs to be explored by the planners and designers.

Hence the aim of this paper is to analyze the building material contribution on the urban microclimate, specially focusing on the pedestrian users. The result of the analysis enable in arriving strategies to improve the microclimatic condition as this will facilitate the architects and planners to design buildings with the understanding of their response to the urban microclimate and comfort of the pedestrian users.

METHODOLOGY

To evaluate the influence of building materials on the urban microclimate of the pedestrian user's two commercial streets of the CBD (Central Business District) is chosen with different orientations. The surface radiation in the streets were calculated for five different time periods. The climatic data was calibrated with an Infrared Thermometer, air temperature and wind speed was calculated with hand held devices. The radiation of the surfaces were calculated through the Stephen Boltzmann Constant. The radiation values were mapped. The radiation values of the individual materials were analyzed for surfaces with different orientation and aspect ratio. The result of the comparison enabled this study to derive strategies that would assist the designers and planners to work on options so as to minimize building material influence on the microclimate the urban pedestrian users. Since the study area is a CBD there was no scope for vegetation. Hence the impact of vegetation on the microclimate of the study area is not considered.

SITE DESCRIPTION

The study was conducted in Tiruchirappalli City (Tamil Nadu , India) located at 10° 48' North and 78° 41' East. The city is at the altitude of 88 m above sea level. The climate of Tiruchirappalli is Hot Humid. The state of Tamil Nadu has a clear climate change scenario. The study was done in the month of April - 2013, based on the IMD report April month has recorded the highest. (*State Level Climate Change Trends in India, Meteorological Monograph No. ESSO/IMD/EMRC/02/2013)*.

Traffic Pattern

The commercial streets (NSB Road, Big Bazaar Street) of the CBD (Central Business District) of Tiruchirappalli City was chosen for the study. The streets are both high density and high rise in character with no scope for vegetation. These streets are significant because they are mostly used by the pedestrians. At the time of festivals like Deepavali and Pongal the streets are completely pedestrianized.

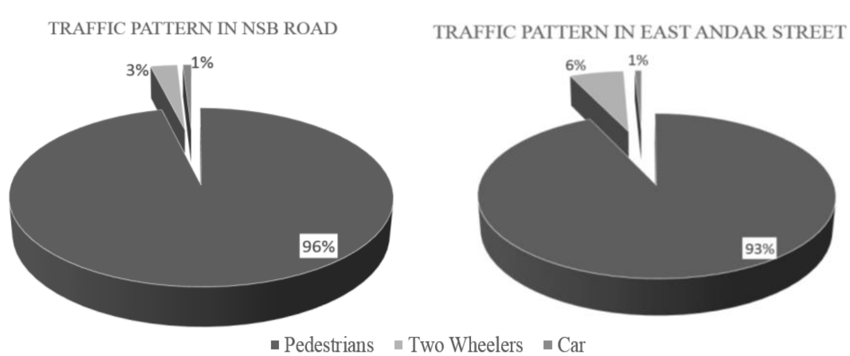


Figure1: Shows the traffic pattern in (a) NSB Road,(b) Big Bazaar Street.

(Source: Tiruchirappalli city Traffic Police)

The buildings of both the NSB road as well as the Big Bazaar Street are of different heights and different surface treatments. The common material used on the building skin are the Aluminum composite panel, Structural glazing (both doubly as well as single glazed layer) and Cement plastered wall with paint. The road surface is made of asphalt.

Figure2: Shows the character of NSB Road

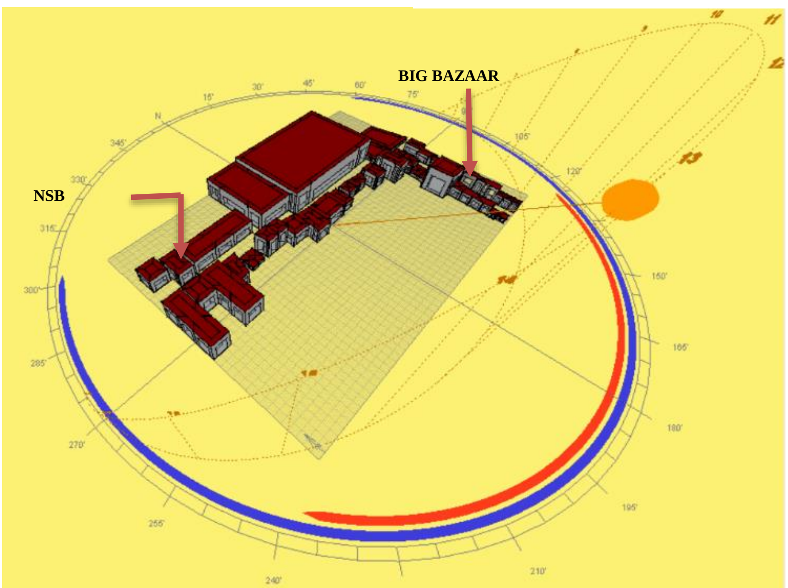


Figure 3: Shows (a) NSB Road (East-West), (b) Big Bazaar Street (North- South) orientation(Ecotect 2011)

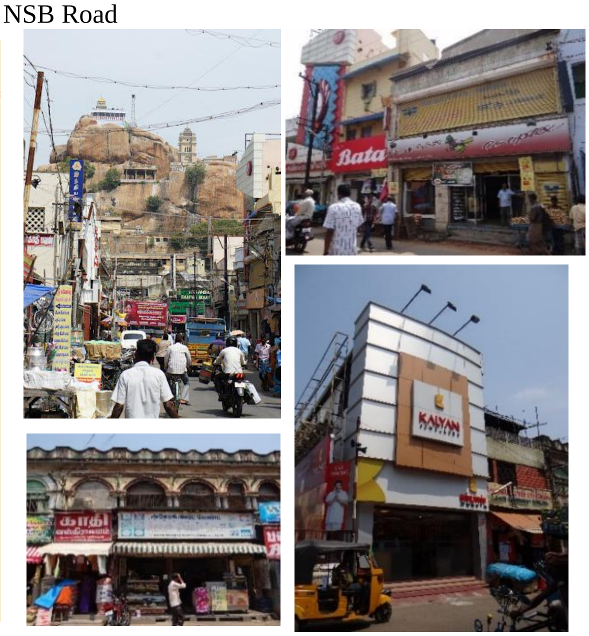


Figure 4: Shows the character of Big Bazaar Street

Solar Access

The urban microclimate is influenced by many anthropogenic induced factors like Pollution, High density construction that cause less wind (A.M. Papadopoulos 2001, B. Givoni 1998) , building material choice (H.Taha,1997),Orientation of buildings,streets (M. Santamouris, N. Papanikolaou ,2001),Lack Of Shading(L. Barring et.al ,1958),Canyon Geometry (S. Yamshita , 1986). The incident solar radiation influences significantly on these anthropogenic factors. Unlike the western countries the right to solar radiation has to be controlled in Tropical country like India to achieve an ambient urban microclimate. The incident solar radiation contributes significantly to the heat transfer phenomenon of the building materials (C. Conner, 1985).

The urban canyon is a more useful city unit for the study of the microclimate of urban environment.

The energy balance of the ‘Earth surface’s – ambient air’ system in the urban environment is governed by the energy gains and losses as well as by the energy stored in the opaque elements of the city, mainly buildings and streets.(M.Santamouris,2001)

$$\textbf{Energy gains = Energy losses + Energy Storage} \qquad (1)$$

Incident solar radiation values are based on two primary components: Direct Radiation from the sun (direct bean radiation = I_b which is always measured perpendicular to the sun's rays. Diffuse radiation that is both scattered by the clouds and atmosphere (diffuse sky radiation = I_d) and the ground in front of the surface (I_r).This is always measured on a horizontal surface.

i.e $$\textbf{Incident Solar Radiation} = (I_b * F_{Shading} * \cos ø) + (I_d + F_{Sky}) + I_r \qquad (2)$$

Where: I_b = direct bean radiation
I_d = diffuse sky radiation
I_r = radiation reflected from the ground
$F_{Shading}$ = Shading factor (1 if a point is not shaded, 0 if a point is shaded, a percentage if measured on a surface)
F_{Sky} = Visible sky factor (a percentage based on the shading mask)
Ø = angle of incidence between the sun and the face being analyzed.

Heat Transfer

The heat transfer phenomenon between the buildings and the environment is very complex (R. Priyadarsini and N.H. Wong, 2005). This phenomenon can be defined on the basis of three basic parameters (A.M. Papadopoulos,2001):

1. The insolation of the buildings, which is a direct function of the orientation, the morphology of the building and the shading factor due to opposite buildings and the existing shading devices;
2. The wind flow in the street canyon that depends on the road's orientation in relation to the prevailing wind direction, the geometric characteristics of the canyon and the temperature conditions on the surfaces of the buildings and the road; and
3. The additional heat emission from local points like the air conditioning systems and the road traffic.

Temperature and Radiation

The three main methods of heat transfer resulting in change of temperature are conduction, convection and radiation. All bodies with a temperature greater than absolute zero radiate energy. Absolute zero is the temperature at which there is no molecular or atomic random motion. It's denoted by 0 Kelvin degrees, which is equivalent to -273.15° C or -459.67° F. Late in the nineteenth century, Stefan experimentally and Boltzmann theoretically developed a relationship between the temperature of a body and the amount of power it radiates.:

To determine outgoing radiation power, we utilize the Stefan-Boltzmann Law

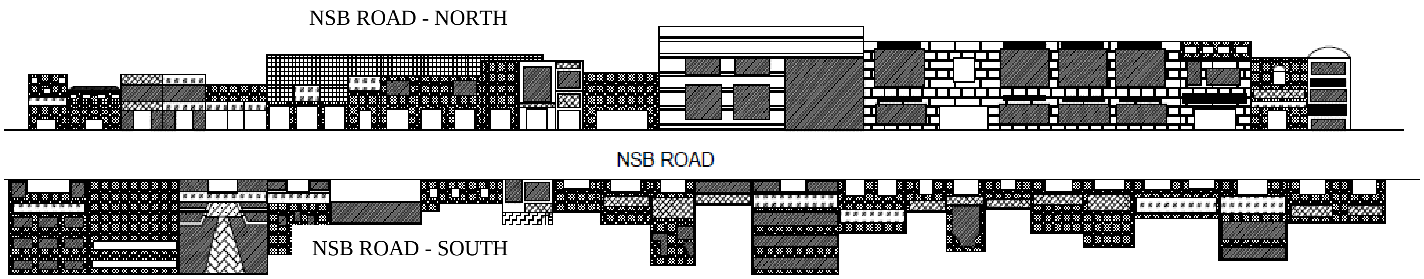
$$P = A\,\varepsilon\,\sigma\,T^4 \qquad (3)$$

Where P (watts) is the radiated power from a body of area A (m2) at temperature T (K).
ε is emissivity
σ is the Stefan-Boltzmann constant, 5.67*x*10-8 Wm-2T-4
T is the body temperature in Kelvin.

Hence the radiation emitted by buildings, streets and all emitting surfaces in the canopy layer can be calculated through the Stefan-Boltzmann Law (M. Santamouris ,et al. , 2001)

Material Map

The materials of the streets are mapped and the area for the individual materials are calculated, the surface temperature of the materials are measured for five different time period (7.00 am,11.00am,13.30 pm,15.00 pm,17.00 pm).



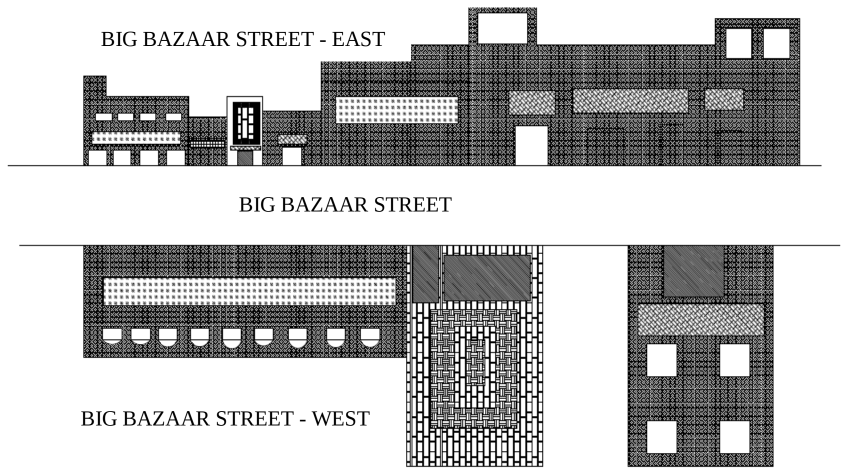


Figure 5: Shows the materials map on the building façade - the streets in elevation.

Observation

The documentation of the building in NSB Road and the Big Bazaar Street resulted in thirteen different materials. (Table 1).

When the radiation of the materials were calculated using Stephen Boltzmann Law, it was observed that due to more emissivity value and substantial percentage of usage in the surfaces, concrete and asphalt contribute significant radiation for all the five time periods analyzed. The radiation value of concrete range between 0.0841W to 0.0878 W and that of asphalt range between 0.042 W to 0.046 W (**Figure 6).**

S.no	Material	Area
1	Concrete	5727.3
2	Glass	1477.14
3	Plastic Board	626.1
4	Flex	674.8
5	Metal	142
6	Granite	9.9
7	Asphalt	2722.9
8	ACP - white	286
9	ACP - Red	87.3
10	ACP – Grey	1391.3
11	ACP - Gold	186.2
12	Gypsum – White	20.3
13	Gypsum - Gold	39.7

Table 1: Shows the materials and the area on the building façade.

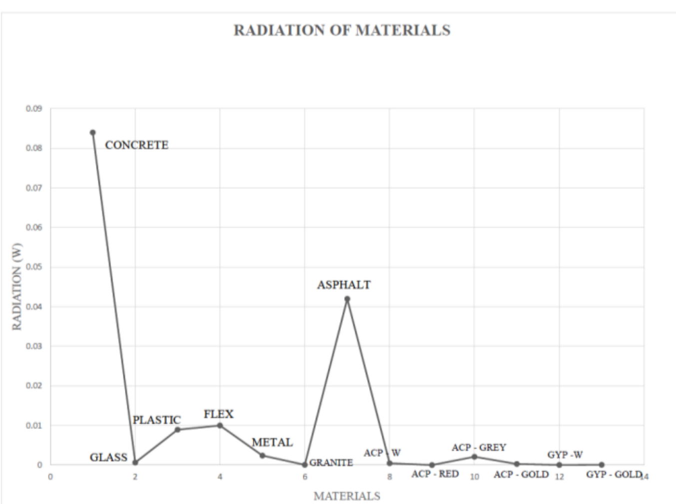


Figure 6: Shows the radiation value of the materials

The surface temperature value of the materials in the NSB Road (East – West orientation) was 3° C more in comparison with that of Big Bazaar Street (North – South Orientation) and this difference was more significant in the early evening time (15.00 pm) when the materials start reradiating the incident radiation. Hence it was evident that the materials in particular, **concrete and asphalt** influence the microclimate of both the streets.

Street Geometry – Materials – Urban Microclimate

This study further explored the relationship between urban canyon and urban microclimate. There were very interesting relationships observed.

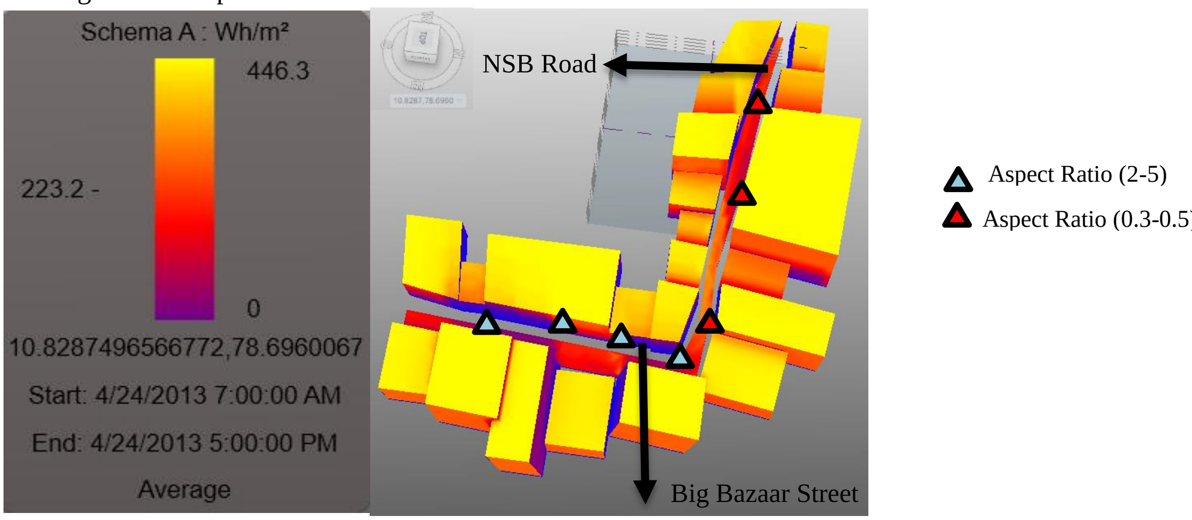
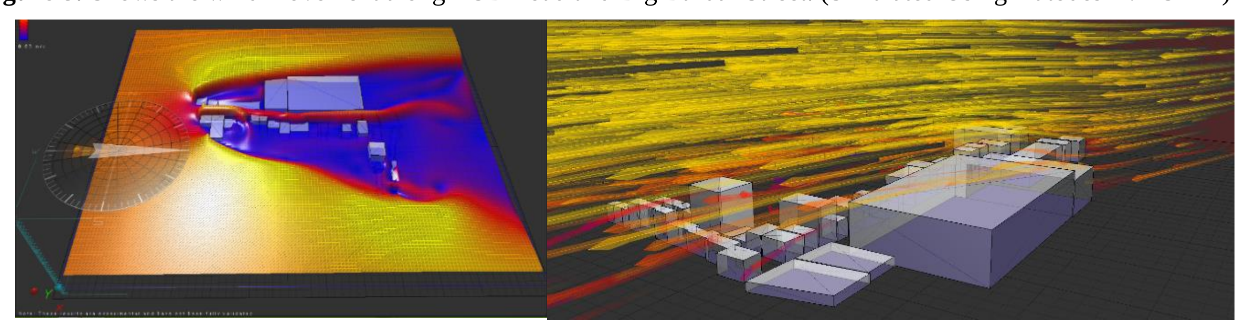


Figure 7: Shows the solar irradiation value of surfaces in NSB Road and Big Bazaar Street. (Simulated Using Autodesk VASARI)

- The open space between the buildings in the Urban Canyons along the East - West orientation streets experienced more radiation on the base surface (roads) compared to that of the vertical surfaces (building façade). This phenomenon was opposite in the urban canyons of the North - South orientation. (**Figure 7**).
- The urban canyons with Aspect Ratios (2 – 5) in both the NSB Road and the Big Bazaar Street had air temperature values less compared to that of the urban canyons with Aspect ratios (0.3 – 0.5). But when the PET (Physiological Equivalent temperature) values were calculated using RAYMAN software for the five different time periods, the values were above the normal comfort range. The PET values (22° C min. - 43° C max), which is much above than the normal range of comfort. (When the comfort range for Tiruchirappalli City was calculated using the weather tool of Ecotect 2011 the range was found to be 26° C - 31° C). The reason behind this discomfort range even in canyons with more aspect ratio is because of very poor wind speed (range between 0.27m/s – 0.54 m/s) due to the high density. When the study area was simulated using the Autodesk Vasari software it was found that practically no wind movement at the height of 2.8m from the ground surface, which is almost the height of the space used by the pedestrians **(Figure 8).**

Figure 8: Shows the wind movement along NSB Road and Big Bazaar Street. (Simulated Using Autodesk VASARI)



- Since Tiruchirappalli belongs to hot humid climatic zone, the problem of humidity was also felt in certain canyons with poor wind movement. Increased air temperature (almost 42° C) and humidity as high as 63% further deteriorated the outdoor comfort condition of the pedestrian users.
- Autodesk Vasari, Ecotect and RAYMAN were all validated with the questionnaire survey. The Percentage of people Dissatisfied were more in NSB Road (East - West) compared to the users of Big Bazaar Street (North – South) for all the five time period **(Figure 9)**.

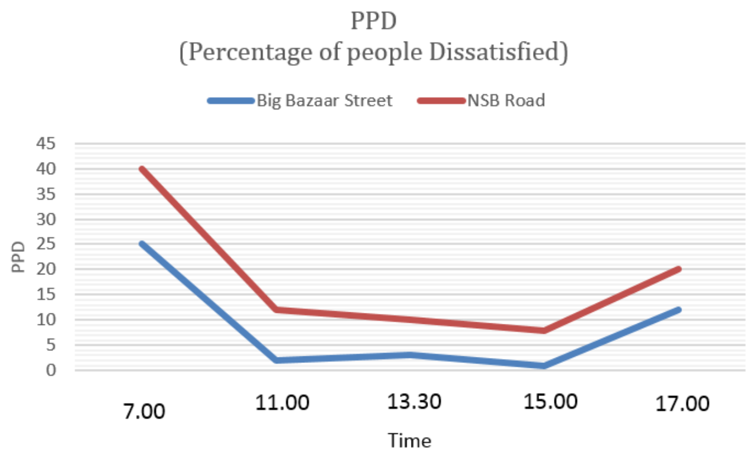


Figure 9: Shows the PPD value for NSB Road and Big Bazaar Street

Design Best Practice Methods

After careful study and analysis of the urban canyon and urban microclimate interactions following design best practice methods were derived **(Figure 10):**

- The choice of building material used on the surface of all planes of urban elements (Base plane – floor, Vertical Plane – walls, Overhead Plane – Building Projections) should be more environment friendly, in radiating heat.
- The street orientation has to be considered while deciding on the material choice for roads. (In the case of NSB road maximum radiation was from the asphalt used on road).
- As how the built space - open space ratios are worked out in 2 – D plans of individual building designs, similar structure has to be considered for the city planning to enable and enhance wind movement. But in areas of high density and high rise buildings like the study area (CBD), outdoor microclimate can be resolved only by providing shading, as wind movement is restricted.
- In order to enhance wind movement among high density built spaces, regulations can be formulated to design buildings with solid and void volumes.

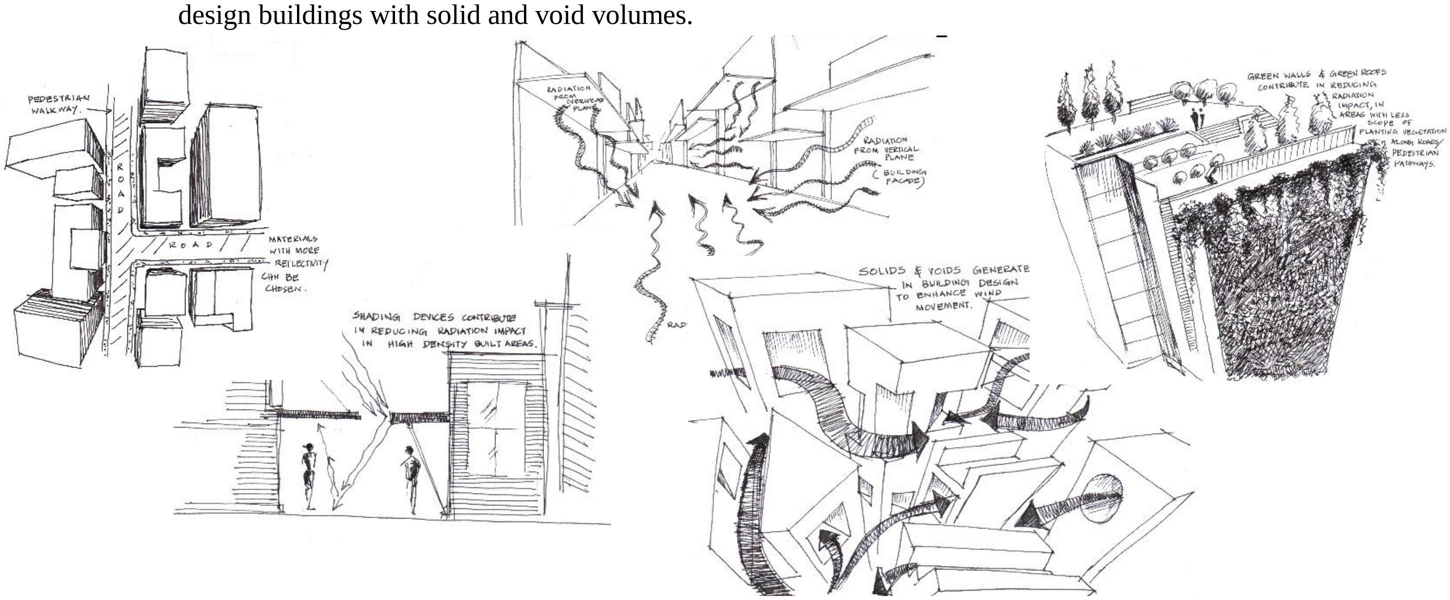


Figure 10: Design best practice methods

- The planning of cities should also consider the 3 - D of the built volumes, since aspects like SVF can be resolved. The canyons can be designed with surface projections and overhanging to reduce the impact of surface radiation of the materials as well they can provide shading for the pedestrian users.
- Since there is less scope of vegetating spaces near buildings , greening of roofs and walls can be done to minimize the impact of radiation.

Conclusion

In a Tropical country like India, where more activity is extended outdoors, climatic comfort of pedestrians is inevitable in the design of urban spaces. Though there are many climatic factors that control urban microclimate, the most important of them is the air temperature, since it directly influences the PET (Physiological Equivalent Temperature). From the study of the commercial streets in the Tiruchirappalli city it was obvious that the air temperature value can be controlled with the help of canyon geometry as well as by enhancing the movement of wind. The increase in wind also offers important role in minimizing the impact of excess humidity in air. These design best practice methods has to be executed right from the level of individual building design to the scale of city design in coherence with the climatic factors. Because the physical factors of the urban canyon and the city climatic factors mutually interact and influence one other. This influence has to be made positive to achieve better comfort condition for the urban pedestrian user.

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Re-evaluation of Passive Design Measures in the BASF House in Recognition of Uncertainty and Model Discrepancy

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ABSTRACT

Located in Nottingham, the BASF house serves as an example for energy efficiency and affordability. The house incorporates a number of passive and active measures to allow thermal comfort for residents. The success of these passive strategies appears to be supported by energy simulation studies. However, before establishing confidence in the results attained by energy simulations, it is critical to understand that energy modelers rely on simulation software to predict building energy performance. Despite the maturity of current energy simulation tools, they are inadequate to make precise predictions for the obvious reasons that local conditions, physical parameters, and usage scenarios are not fully known. As a consequence, passive design measures may fail to achieve their expected benefits. Indeed, models may show predictions that deviate from what we would observe in the realized building. The primary cause of such deviation is uncertainties in the model parameters and formulations. The important question to be raised is whether the recognition of the performance gap between design and reality would lead us to rethink the applicability of passive design measures. This paper focuses on analyzing the impact of those uncertainties on the evaluation of passive design measures in the BASF house. The exploration focuses on the risk that a passive design solution may cause unacceptable discomfort, which could potentially lead to its rejection despite its initial selection based on the results of a conventional energy simulation. This level of understanding is essential if we are to make rational design decisions regarding the applicability of passive strategies.

INTRODUCTION

In 2007, BASF, a German chemical company devoted to energy efficiency and resource protection, initiated a project to design, construct, and test modern methods of construction in six innovative, flexible houses. The first to be completed was the BASF house, located in Nottingham, England. Built in wet, cold weather, the house contains both active and passive strategies, the latter of which play a crucial role in establishing thermal comfort of residents.

Passive Strategies

Passive design arises with the desire to maximize thermal and environmental benefits. Building designers need to thoroughly investigate the thermal characteristics of building components and systems to determine the optimal solution to minimizing heat loss in the winter and heat gain in the summer. Although a purely "passive" design without any mechanical intervention is preferable in terms of energy, more often than not, it does not meet the thermal comfort requirements, leading to the creation of hybrid systems, that is, incorporating mechanical devices into passive elements allowing the latter to function appropriately. One example is the BASF house, which combines a range of strategies such as shading, buffer zones, compactness, highly insulated building fabric, and double-glazed windows, as well as phase-change materials on the ceiling, an earth-air heat exchanger for cooling and pre-heating air, and natural ventilation in order to achieve desired performance.

Earth-Air Heat Exchanger

Earth air heat exchangers, buried to moderate depths, are generally underground horizontal ducts or pipes in which outside fresh air or re-circulated air is conditioned by the thermal mass of the earth and channeled into the house. To enhance heat transfer, pipes are usually made of polypropylene.

Phase-Change Materials

Because of their high storage density and latent heat property, phase-change materials are critical in the thermal energy storage of the building envelope system. One of the potential applications for phase-change materials is to incorporate them into the envelope system in buildings for energy conservation. During the summer, benefits include a time shift in the thermal load during the day and thus a decrease in the peak temperature. Since they will help reduce cooling loads by absorbing heat during the day and recycling it during the night, it is hypothesized that phase-change materials will work efficiently in the climate of Nottingham with warm days and cold nights.

A METHODOLOGY FOR EVALUATIING PASSIVE MEASURES UNDER UNCERTAINTY

To evaluate the performance of passive strategies, designers base their decisions on energy simulation results to predict building behavior after implementation. However, when predicting the performance of buildings, current building performance assessment tools do not account for risks that can lead to designers' having false confidence about the expected performance of sustainable measures and an impression about the likely underperformance of passive houses in reality. Mlakar and Strancar (2011), and Rodrigues and Gillott (2011) showed problems of overheating in passive houses during operation in the summer with in-situ measurements. Furthermore, Larsen and Jensen (2011) acknowledged that possible problems with high indoor temperatures are not anticipated during the design process via simulations but observed after the building is finished at the site. These findings motivate us in proposing a methodology for evaluating passive design measures with a clear indication of the risks of indoor discomfort. Additional risk information will infuse confidence about the effectiveness of proposed design measures for improving the thermal comfort of a passive house.

The probability that an unfavorable event will occur is referred to as "risk." To measure risk, one must analyze the indefinite nature of the outcome of a situation, or uncertainty. Such is the case in predicting building performance, which entails two main sources of uncertainty. The first is uncertainty related to the physical properties of building components, system parameters, and operational scenarios. For example, the performance of building HVAC systems generally deviates from their nameplate efficiency, which stems from industrial compliance tests. Instead, their on-site performance may vary, depending on the local environments and construction and installation circumstances such as the effect of bad workmanship. Another source of uncertainty is the reliability of the model itself. Current most state-of-the-art energy simulation tools represent complex physical processes in reality through certain levels of abstraction and simplification. In addition, the modeler has to make assumptions resulting from a lack of information or expertise, which can lead to an overstatement of performance. In reality, no model can capture all aspects of a system and predict its full spectrum of performance during operation. The need to translate the identified uncertainties to risks has called for a type of uncertainty analysis that quantifies the impact of physical parameter uncertainties, modeler assumptions, and model simplifications on the outcomes. Such an analysis is typically carried out using a Monte Carlo approach with an appropriate sampling technique in order to increase computational efficiency. The Monte Carlo (MC) simulation uses random number generators to model stochastic event occurrences.

de Wit and Augenbroe (2002) and MacDonald (2002) introduced a general procedure for uncertainty analysis of building thermal performance. Khazaii (2012) studied different sources of HVAC system uncertainty such as equipment manufacture tolerance, system degradation, and duct leakage. Wang, Augenbroe and Sun (2014) quantified the impact of realization uncertainty of construction detailing and workmanship on building energy performance. Their studies showed that a quantitative uncertainty assessment is essential in a design decision making process. These efforts represent only a small slice of a growing body of work that studies the effect of uncertainties encountered at various model levels (e.g., micro-climate, building level, and system level). Referring to the above sources, this paper uses the parameter uncertainty quantifications and techniques.

This paper casts new light on the evaluation of passive design strategies, which will explicitly show risks associated with design decisions. It will provide designers with quantitative evidence that certain levels of building performance will be accomplished or not. In this study, we propagate uncertainties through GURA-W (Georgia Tech Uncertainty and Risk Analysis Workbench) (Lee, Sun, Augenbroe and Paredis 2013). The probability distributions of uncertainty parameters are contained in an XML repository and sampled with Latin hypercube sampling. We then feed these uncertainty parameters into an EnergyPlus simulation engine. Eventually, the simulation results will show the performance of passive design strategies and their associated risks. The following sections present a case study showcasing the validity and value of our proposed methodology.

BASF HOUSE AND MODEL ASSUMPTIONS

The BASF house has an area of about 100 m^2 divided into ground and first floors as depicted in Figure 1. The ground floor mainly consists of an open-plan living room and a kitchen with a staircase connected to the first floor, allowing natural ventilation from the stack effect. The first floor comprises of two main southern bedrooms and a smaller one on the north (unoccupied). The house has a fully glazed double-height southern sunspace with external shading and internal adjustable blinds. Openings are carefully placed around the house, facilitating optimal use of natural cooling in the summer.

Figure 1. the BASF house

In terms of construction methods, ground floor walls are made of insulated concrete formwork (ICF) while the first floor walls and the roof are constructed of structural insulated panels (SIPs). In total, 100 m^2 of PCM boards that store and release heat from the living room, bedrooms, and the sunspace are sandwiched between plasterboards and oriented strand boards (OSB). Windows and curtain walls are double glazed and filled with argon with a U-value of 1.66W/m^2K. The interface between multiple construction methods eliminates easily avoidable thermal bridges. In addition, the air permeability of the house is addressed by incremental pressurization tests and vulnerable area treatment, so the final house is among the most airtight in the United Kingdom (3.38m^3/h/m^2 at 50 Pa). An earth air heat exchanger containing 36m of piping buried at a depth of 1.5m supplies 0.05 m^3/s of precooled or preheated air to the sunspace from 11am to 5pm and to the living room from 12pm to 2pm.

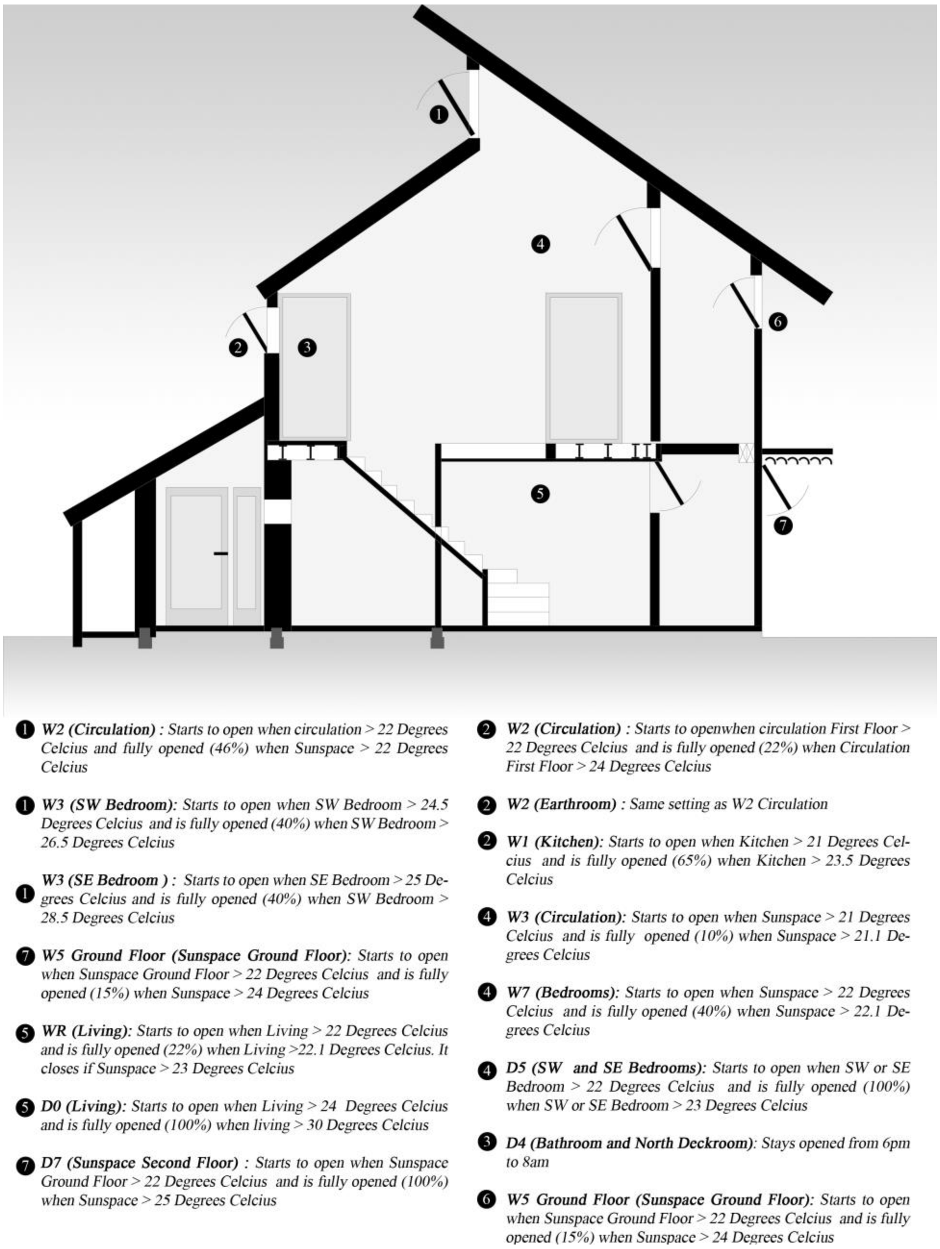

Figure 2. Ventilation strategy in the BASF house

The development of thermal models requires a series of further assumptions. Information on construction types, occupancy schedules, and internal heat gains are loyal to the design intention and onsite implementation. PCM boards are simulated using the conduction finite difference solution algorithm in EnergyPlus, which uses an implicit finite difference scheme coupled with an enthalpy-temperature function to account for phase-change energy accurately. The local soil type is assumed to be standard (density 1800kg/m^3, conductivity 1.45W/mK, and thermal diffusivity 6.015×10^{-7}m^2/s) in the calculation of the average temperature, the amplitude and the phase constant of the soil surface. Then the performance of the earth-air heat exchanger is determined given these boundary conditions. Figure 2 showcases the ventilation strategy. More information about the BASF house can be found in Rodrigues (2010).

RE-EVALUATION OF MEASURES IN THE BASF HOUSE

Following the previous reasoning, risks associated with passive design strategies cannot be thoroughly understood without acknowledging the uncertainties. Uncertainty analysis can provide information with respect to whether investigated strategies can meet the comfort requirement with a specific degree of confidence, for instance expressed as a discomfort risk tolerance such as the allowed probability that the number of discomfort hours is exceeded. Rodrigues and Gillott (2011) compared deterministic simulation results with actual measurements for the BASF house and concluded that the simulation results are similar to the actual measurements except that the former over-predict the overheating issue in the sunspace and underestimate it in the north bedroom. The recorded observations seem to strengthen our argument that relying totally on deterministic results may give rise to false confidence and be insufficient in supporting design decision making. Therefore, the proposed design measures for the BASF house must be reevaluated under uncertainty. As an example, this study analyzes the risk of overheating in July, when the peak temperature might occur in Nottingham.

Risk of Overheating

According to CIBSE, the benchmark for overheating is 26°C in the living room and 25°C in the bedroom. If the benchmark is exceeded, the duration of the time above 28°C in the living room and 26°C in the bedroom should be no longer than 1%. Therefore, we first take the percentage of occupied time (12am to 9am, 5pm to 12am on weekdays; all the time on weekends) outside the above comfort zone as the performance indicator to evaluate the risk of overheating in the BASF house. Another way to rate discomfort is the absolute number of hours that a certain threshold is exceeded during a given critical month. The following results can be easily translated to the absolute number of hours in July by realizing that 1% corresponds to 5 to 6 hours. It should be noted that in order to identify if certain measures could fail the comfort tolerance of future occupants, a risk conscious measure will have to be established. If, for the sake of the argument, we assume that the risk tolerance of the occupants is that in the southwest bedroom in July, the probability that the number of discomfort hours above 28°C exceeds 35 (or 6% of the occupied time) cannot be higher than 8%, we would see that the current design would be acceptable based on Figures 3a and 3b. Figure 3a shows the distribution of the number of hours in July, when the temperature in the southwest bedroom exceeds 28°C during occupied hours. The predicted range is the combined effect of the uncertainties mentioned above. In Figure 3b, the error bar represents the 90 percent confidence interval of the quantity of interest. For example, for the southwest bedroom, the bar chart suggests with 90% confidence that the percentage of time during which the indoor temperature is higher than 25°C will be between 16.3% and 26% with a median value of 20.6%. The measurement data from Rodrigues and Gillott (2011) are in close agreement with the confidence interval predicted through our uncertainty analysis, confirming the validity of our model.

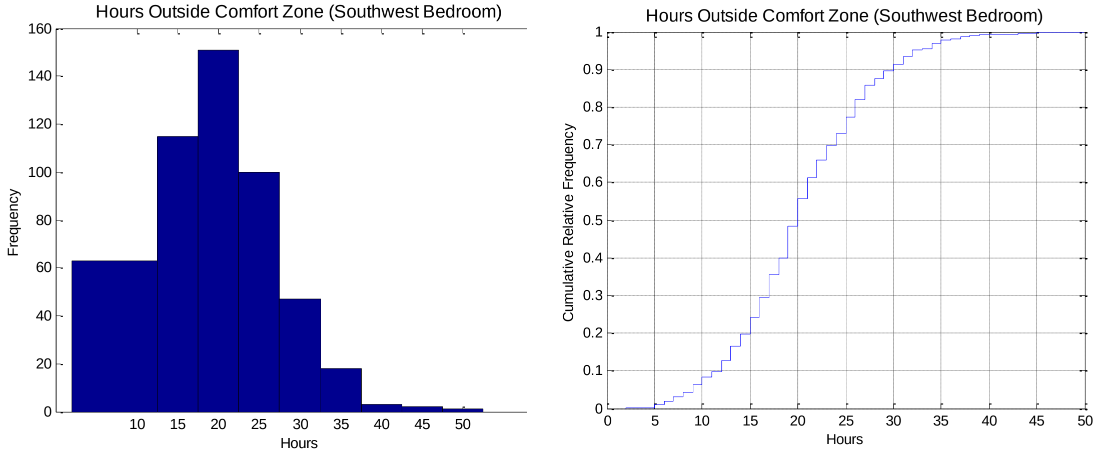

Figure 3a. Histogram (left) and cumulative relative frequency (right) of hours of discomfort in July

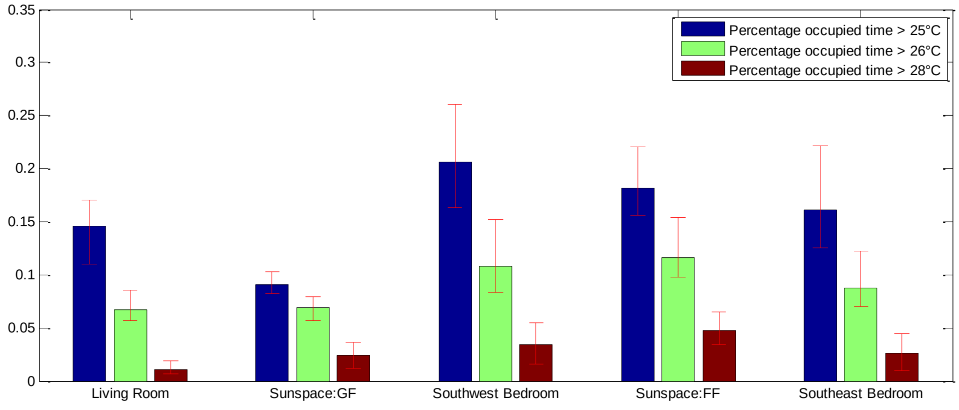

Figure 3b. Percentage of time outside the comfort zone with a 90% confidence interval (base case) in July

Effectiveness of EAHE

Since the EAHE ventilates only the living room/kitchen area and the sunspace on the ground floor and because the benefits of natural ventilation in the bedrooms through open doors have not been proven, this section simulates the model developed previously without including the EAHE module to validate its effect. The EAHE supplies 0.05 m^3/s of precooled or preheated air, which translates to 0.68

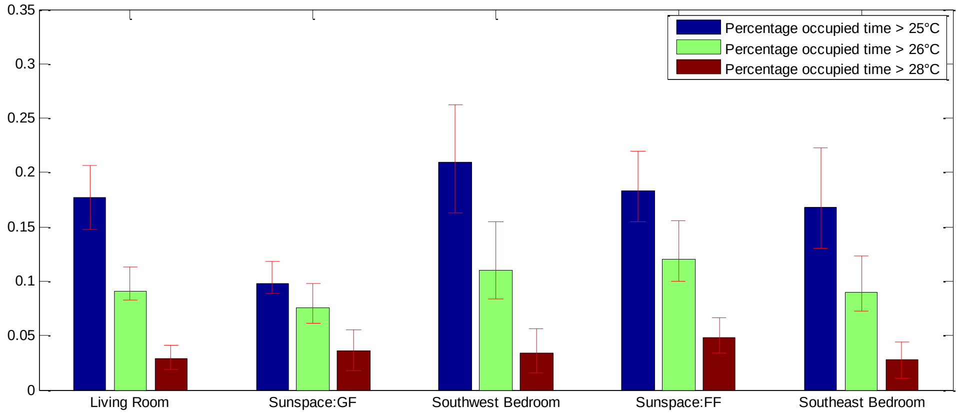

Figure 4. Percentage of time outside comfort zone with 90% confidence interval (no EAHE) in July

ACH for the living room/kitchen areas and 2.6 ACH for the ground floor sunspace. As the results show (Figure 4), these two areas benefit most from the EAHE air supply: While the percentage of time exceeding the comfortable temperature of 25°C in the living room increases from 11% ~ 17% to 14.8% ~ 20.7% without the EAHE, that in the sunspace increases only slightly from 8% ~ 10.3% to 9% to 11.8%. Only a minor impact on the rest of the house suggests the intended air movement by design might need a more sophisticated fluid dynamics model to guide and validate it.

Effectiveness of PCM Boards

Rodrigues and Gillott (2011) observed that PCM boards are not below their phase-changing zone long enough to completely release the heat they absorb on a daily basis, which may undermine their effectiveness. Their work in TAS for the BASF house is incapable of simulating the effect of the PCM boards, leaving several hypotheses unproven.

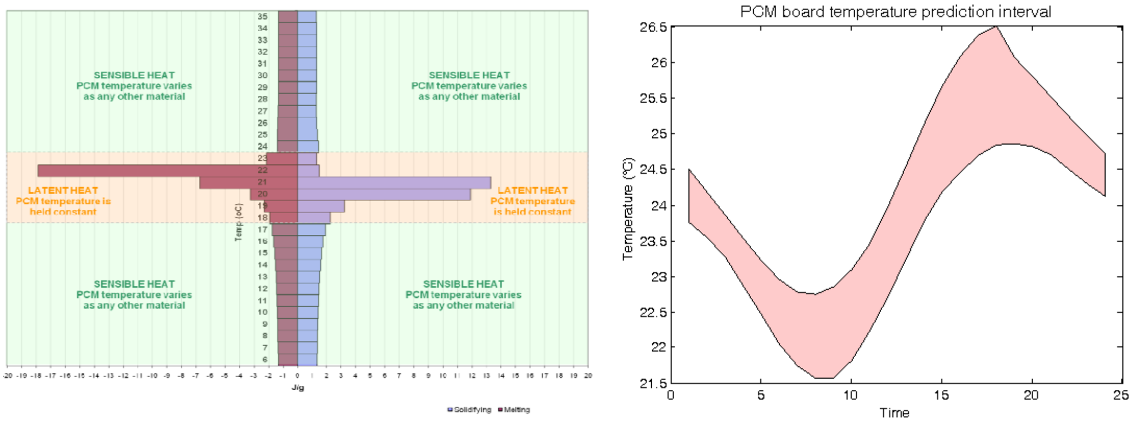

Figure 5. Properties of PCM boards (left) and the prediction intervals of their temperatures (right)

According to the product specs from Rodrigues (2010), the operating temperature of the Micronal Knauf SmartBoard 23 is between 19°C to 23°C, and the maximum enthalpy slope is at 20°C. Figure 5 shows the prediction interval of the temperatures of the PCM boards in the living room on July 1. For example, their minimum temperature (around 8am) could be somewhere between 21.6°C to 22.8°C instead of a deterministic value. Unfortunately, PCM boards exceed their phase-changing temperature most of the time without major solid-liquid transitions. Therefore, they are not very effective in absorbing excessive heat from the room. Our finding supports the original argument by Rodrigues and Gillott (2011).

Exploring Ventilation Strategies

In this section, we test how the previous outcome is sensitive to the ventilation strategy presented in Figure 2 to account for another layer of uncertainty resulting from occupancy and use. We confine the ventilation air exchange rate per hour for each room as no larger than 15 for exterior spaces and 10 with adjacent spaces, which mimics the window/door closing behavior of users in case of undesirable effects such as a draft. Compared to the results in Figure 2, those in Figure 6 show only minor differences. However, for the southwest bedroom, the risk tolerance of occupants is exceeded: the probability that there are more than 35 occupied hours that the temperature exceeds 28°C is higher than 8%. We could conclude from the variability of outcome that the current design given the more realistic ventilation strategy would be unacceptable assuming the above risk tolerance of occupants.

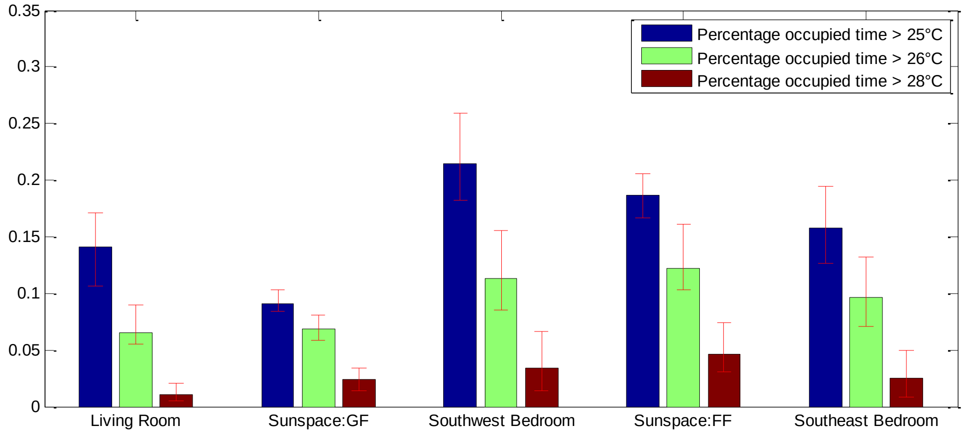

Figure 6. Percentage of time outside the comfort zone with a 90% confidence interval (ventilation)

CONCLUSION

The contribution of this paper is that we have proposed a methodology for evaluating the effectiveness of passive design strategies under uncertainty. Given the risk tolerance of the intended occupants of the building, this methodology enables risk conscious design for clearly identified risk measures. Although the analysis in the study was confined to the BASF house, the proposed method has generality to guide future practice. We simulated passive measures in the BASF house and inferred the variability of uncertainty parameters from previously published work. The dynamic energy simulations led to the following conclusions:

(1) Our proposed methodology excels in the following ways: It is able to predict the probability of the occurrence of extreme conditions inside buildings such as overheating while the conventional simulation approach cannot; the merit of different design options could be assessed against an occupant specific discomfort tolerance which will lead to superior decision making on which measures improve on the current design and which do not. We have demonstrated this point by showing that for a reasonably chosen, explicitly defined discomfort risk tolerance of an occupant, the BASF house would be deemed unacceptable. Such outcomes would have necessitated the BASF design to undergo additional measures that reduce the risk to fall within the tolerable range.

(2) In terms of the earth-air heat exchanger, with the current limited operation time, it does not address the problem of overheating in the bedrooms although the comfort level in the living/kitchen area improved: The occupied time period when the temperature was higher than 25°C declined by 17% on a median level. The PCM boards did not contribute significantly to maintaining indoor comfort during the summer because of the lack of sufficient natural cooling to discharge stored heat. Thus, we recommend that designers have a good sense of the operating temperature range before choosing a specific product. In addition, we found the ventilation strategy an important piece of our jigsaw puzzle of maintaining a desirable indoor environment with passive measures. Even when the exterior condition is appropriate for natural cooling, the fact that an over-ventilated space with drafts could be as uncomfortable as an overheated one, may deem some passive designs unacceptable after all. Discomfort from drafts can be assessed with an uncertainty analysis of the airflows using a CFD model, which could be a topic of future work.

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Life Cycle Assessment as a tool for Material Selection - A comparison of Autoclaved Aerated Concrete and VSBK Brick Wall Assembly.

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1.0 ABSTRACT

Energy use of a building can be derived from five sources: Embodied Energy from mining and manufacturing of materials, Energy from transportation of materials, Energy from construction of the building, Energy use during operation of the building, and Energy used in the disposal of the building at the end of its life. Buildings use many materials with a high Embodied Energy, and it is estimated that, 10% of its total energy use comes from Embodied Energy in materials. Thus, the use of low Embodied Energy Materials for the sustainable development is preferred. Life cycle assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of buildings materials, buildings and its products through all of its life stages.

Brick and Cement are majorly used materials in building industry. Kiln Burnt Brick is majorly use exterior wall material in the market. Also, Aerated Concrete (AAC) is a non-combustible, cementitious building material that is expanding into new worldwide markets.

The Paper will be aimed to compare the environmental impact of materials- Kiln Burnt Brick and Autoclaved Aerated Concrete used for wall assemblies. Study will be focused on evaluating the materials with respect to its Embodied Energy, Energy and Resource consumption, Environmental Impact in terms of CO2 Emissions, Cost, Health safety etc. The functional unit and unit distance will be defined to allow comparisons to be made between materials. The study will include interaction with the Manufacturers, Market study of the materials, and use of material in a particular building. The final objective of the paper is to evaluate the materials on the bases of Life Cycle Assessment Impact Categories which includes: Raw Material Index (RMI), Water consumption, Embodied Energy (EE) and Operational Energy (U-Value), Electricity, Occupational Health and Safety (OHS Index), Total Cost, CO2 Emissions.

Key words: - Life Cycle Assessment, Materials, Kiln Burnt Brick, Autoclaved Aerated Concrete, Life Cycle Assessment Impact Categories.

2.0 INTRODUCTION

Building construction in India is estimated to grow at a rate of 6.6% per year between 2005 and 2030 (McKinsey and Company, 2009). The building stock is expected to multiply five times during this period, resulting in a continuous increase in demand for building materials, which could have long lasting implications in terms of natural resource depletion, future energy demand, local pollution, contributions to greenhouse gas emissions as well as socio-economic conditions of a significant number of low-income workers. Thus it is an imperative and urgent need to have a comprehensive plan for development of walling materials production in India, with the least impact to the earth.

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All materials have environmental implications. Thus the choice of materials for a project requires considerations of aesthetic appeal, initial and ongoing costs, life cycle assessment considerations (such as material performance, availability and impact on the environment) and the ability to reuse, recycle or dispose of the material at the end of its life. It is estimated that, 10% of buildings total energy use comes from embodied energy in materials. Thus, the use of low embodied energy materials for the sustainable development is preferred. Life Cycle Assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of buildings materials, buildings and its products through all of its life stages from cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

Brick and Cement are majorly used materials in building industry. Kiln Burnt Brick is majorly use exterior wall material in the market. Also, Aerated Concrete (AAC) is a non-combustible, cementitious building material that is expanding into new worldwide markets.

3.0 AIM AND OBJECTIVE

The Paper is aimed to compare the environmental impact of materials- Kiln Burnt Brick and Autoclaved Aerated Concrete used for wall assemblies.

The final objective of the paper is to evaluate the materials on the bases of Life Cycle Assessment Impact Categories which includes: Raw Material Index (RMI), Water consumption, Embodied Energy (EE) and Operational Energy (U-Value), Electricity, Occupational Health and Safety (OHS Index), Total Cost, CO2 Emissions.

4.0 METHODOLOGY

In this assessment the tools of Life Cycle Assessment are integrated, which includes due consideration of all life cycle stages fixed in the ISO 14040 –14043 standards: Goal and Scope Definition, Life Cycle Inventory Analysis, Life Cycle Impact Assessment and Life Cycle Interpretation.

Life Cycle Inventory Analysis includes assembling data and analyzing it on a suitable system boundary. Life Cycle Impact Assessment is the evaluation of the material and energy flows raised in the inventory analysis according to certain environmental effects.

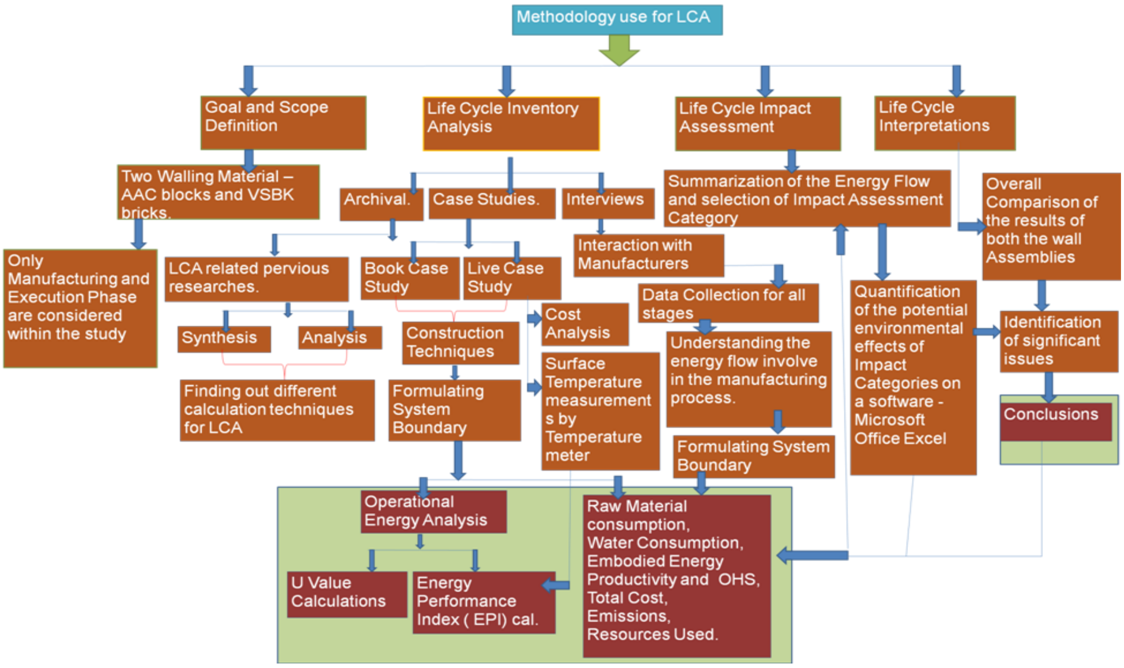


Figure 1 *Methodology use for Life Cycle Assessment.*

Thenafter, Impact Assessment categories are selected, which includes: Raw Material Index (RMI), Water Consumption, Embodied Energy (EE) and Operational Energy (U-Value), Electricity and other Resources, Occupational Health and Safety (OHS Index), Total Cost, CO2 Emissions. Life Cycle Interpretation consists of Identification of significant issues, evaluation and conclusions.

5.0 SCOPE AND LIMITATION

Study is focused on evaluating only two walling materials - Kiln Burnt Brick and Autoclaved Aerated Concrete with respect to its formulated Impact Assessment Categories. The functional unit and unit distance is defined to allow comparisons to be made between materials. The study includes interaction with the Manufacturers, Market study of the materials, and use of material in a particular building.

Building use: Evaluation of the materials and energy consumptions is restricted to the use of a building only, its maintenance and restoring, not considered within this study. Also, Transport of the wastes generated during the Construction and Demolition phase, not considered within this study. No consideration of labour cost as it will have negligible effect on the results.

To understand the implication of these materials, the live site data collection is limited to pune (moderate climate), but to understand the impact of operational energy a theoretically comparative study base has been done with a case study of composite climate.

6.0 LIFE CYCLE ASSESSMENT

A Life Cycle Assessment (LCA) provides a mechanism for systematically evaluating the inputs, outputs and the potential environmental impacts linked to a product or process throughout its life cycle. (ISO 14040). LCA addresses the impacts of a product through all of its life stages.

Life Cycle Assessment is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave.

6.1 EMBODIED ENERGY

Embodied energy is the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site. Energy consumption produces CO2, which contributes to greenhouse gas emissions, so embodied energy is considered an indicator of the overall environmental impact of building materials and systems. It does not include the operation or disposal of materials.

The total amount of embodied energy may account for 20% of the building's energy use, so reducing embodied energy can significantly reduce the overall environmental impact of the building.

Energy consumption during manufacturing can give an approximate indication of the environmental impact of the material, and for most building materials, the major environmental impacts occur during the initial processes.

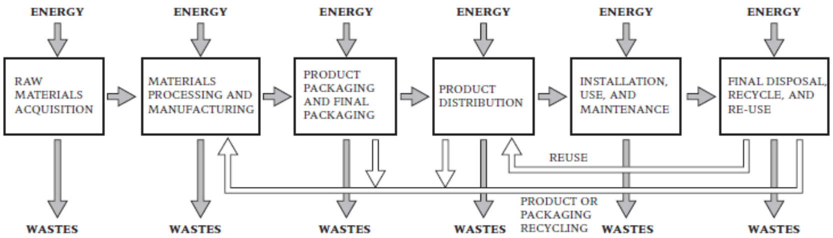


Figure 2 *Typical phases of materials Life Cycle, along with inputs and outputs at each phase.*

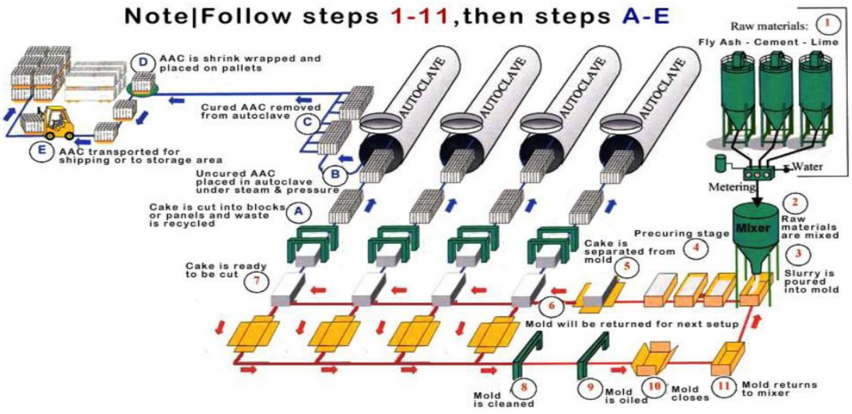
7.0 LIFE CYCLE INVENTORYANALYSIS OF AAC BLOCKS AND VSBK BRICK

7.1 Autoclaved Aerated concrete and Vertical Shaft Brick Kiln (VSBK)

AAC is lightweight, precast building material that simultaneously provides structure, insulations, and fire & mold resistance. Main ingredients include fly ash, water, quicklime, cement, aluminium powder & gypsum. The block hardness is being achieved by cement strength, & instant curing mechanism by autoclaving. Gypsum acts as a long term strength gainer. The chemical reaction due to the aluminium paste provides AAC its distinct porous structure, lightness & insulation properties, completely different compare to other lightweight materials.

The VSBK is a vertical kiln with a stationary fire and a moving brick arrangement. The figure below shows the VSBK principle in a schematic diagram. The kiln operates like a counter current heat exchanger, with the heat transfer taking place between the air moving upwards and the bricks moving downwards.

(a)

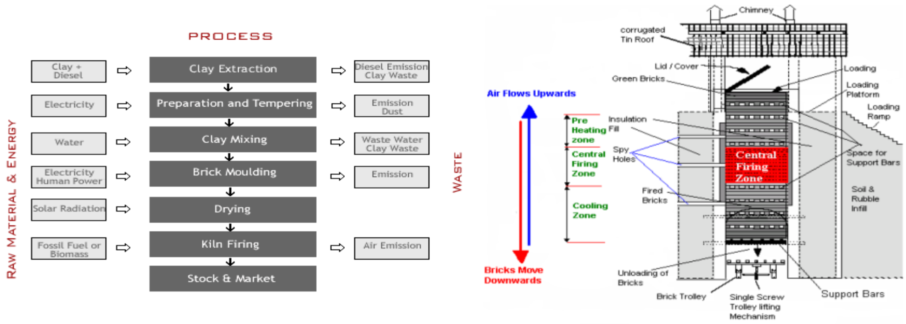


(b)

Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
Quantities of AAC Wall yearly 100000 cum						
lime	90.00	kg/cu.mt	5.63	Mj/kg	506.7	Mj
fly ash	450.00	kg/cu.mt	0	Mj/kg	0	Mj
Cement	70	kg/cu.mt	4.2	Mj/kg	294	Mj
aluminium powder	0.5	kg/cu.mt	260	Mj/kg	130	Mj
gypsum	5	kg/cu.mt	1	Mj/kg	5	Mj
Total RM EE					**935.7**	Mj
Transport	150	Km.	11.93	Mj/Km.	1789.5	Mj
Total					**2725.2**	Mj
electricity (kWh)	9	kWh/Cu.m.	9.28	Mj/kWh	83.52	Mj
Coal (kg)	0.03	ton/cu.mt	12.3	Mj/ton	0.369	Mj
Total					**2809.09**	Mj
Water consumption	400	l/cu.mt				
human resource	60	no.s	10.04	Mj/day	602.4	Mj
0.098Kg of CO2 per MJ of embodied energy					**275.29**	CO_2/cu.m

Figure 4 *(a) Process Flow Chart and (b)* ***Table 1*** *Embodied Energy calculations for AAC Block Production.*

Note: Data Collection for production process of AAC Blocks is taken from company Anjali Ventures Ltd., Surat.



(a)

Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
Quantities of Brunt Bricks (brick weight is app 3kg)						
Fired Brick	555.00	**unit/cu.mt**	7.9	**Mj/unit**	4384.5	Mj
Total RM EE					**4384.5**	Mj
Transport	50	Km.	11.93	Mj/Km.	596.5	Mj
Total					**4981**	Mj
electricity (kWh)	1	kWh/Cu.m.	9.28	Mj/kWh	9.28	Mj
Coal (kg)	6	ton/cu.mt	18	Mj/ton	108	Mj
Total					**5098.28**	Mj
Water consumption	420	l/cu.mt				
human resource	9	no.s	10.04	Mj/day	90.36	Mj
0.098Kg of CO2 per MJ of embodied energy					**499.63**	CO_2/cu.

Energy content of furnace oil = 42.25 MJ/l; energy content of grid electricity = 9.28 MJ/kWh; and energy content of cement = 4.20 MJ/kg,All Embodied Energy reference: http://besharp.archidev.org/IMG/pdf/Embodied_Energy_Computations_in_Buildings.pdf

Figure 5 *(a) Process Flow Chart and (b)* ***Table 2*** *Embodied Energy calculations for VSBK Block Production.*

Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
Quantities of AAC Wall						
Volume of wall	**107.54**	**Cu.m.**				
Volume Green mortar	2.15	Cu.m.	3.2	Mj/cu.m.	6.88	Mj
Cement	0	Cu.m.	5999.7	Mj/cu.m.	0	Mj
Transport	150	Km.	11.93	Mj/Km.	1789.5	Mj
Total					1796.38	Mj
Sand	0	Cu.m.	29.58	Mj/cu.m.	0	Mj
Electricity	2	kWh	9.28	Mj/kWh	18.56	Mj
size(625 x 250x 150	0.023438	Cu.m.	42.67	blocks/ cu,mt		
No.s of blocks	4229.96	no.s/cu.mt	65.84	Mj/Block	2809.09	Mj
Total					**4624.03**	Mj
E.E. of total wall					**497274.64**	Mj
0.098Kg of CO2 per MJ of embodied energy					**48732.91**	kg of CO_2

(a)

Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
Quantities of brick Wall						
Volume of wall	**107.54**	**Cu.m.**				
Volume mortar	3584.71	Cu.m.			479.14	Mj
Cement	0.07	Cu.m.	5999.7	Mj/cu.m.	419.98	Mj
Transport	50	Km.	11.93	Mj/Km.	596.5	Mj
Sand	2.00	Cu.m.	29.58	Mj/cu.m.	59.16	Mj
Electricity	4	kWh	9.28	Mj/kWh	37.12	Mj
Total					1112.76	Mj
size(230 x 110 x 70 mm)	0.001771	Cu.m.	555 brick in 1 cu.mt			
No.s of blocks	44530.58	no.s	9.03	Mj/Block	5098.28	Mj
Total					**6211.04**	Mj
E.E. of total wall					667944.10	Mj
0.098Kg of CO2 per MJ of embodied energy					**65458.52**	kg of CO_2

(b)

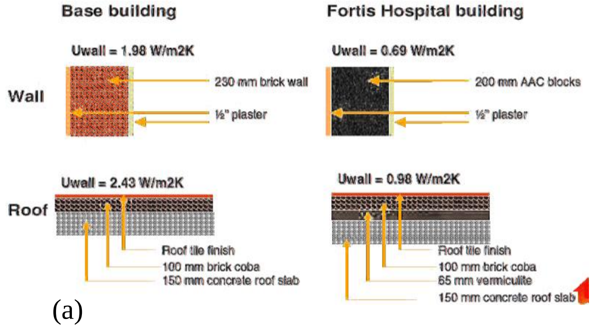
Source: - embodied energy of various materials and technologies - data and summary - 1.pdf
About 0.098 tonnes of CO2 are produced per gigajoule of embodied energy = 0.098Kg of CO2 per MJ of embodied energy

Table 3 *Embodied Energy calculations involved in constructing the Wall Assembly of AAC amd VSBK.*

8.0 CASE STUDIES (CLIMATE: COMPOSITE CLIMATE)

8.1 Fortis Hospital – 3 Star rated. (Location: Shalimar Bagh, New Delhi)

The 500 bedded Fortis hospital at Shalimar Bagh is designed with a vision to provide an environment friendly health care facility in an area of 64,400 sq mts. It is the first hospital building in India to have registered for the GRIHA green building rating system.



(a)

	Base building	Fortis hospital, Delhi	ECBC recommended
1. Building Envelope			
External wall	230 mm brick work plastered on both sides U-value = 1.98 W/m²K	Cement plaster + 200 mm AAC blocks + cement plaster U-value = 0.69 W/m²K	U-value = 0.44 W/m²K
Roof	150 mm concrete roof slab + 100 mm brick coba + roof tile finish U-value = 2.43 W/m²K	150 mm concrete roof slab + 65 mm vermiculite + 100 mm brick coba + roof tile finish U-value = 0.98 W/m²K	U-value = 0.409 W/m²K
Glass	Single clear 6mm glass U-value = 5.7 W/m²K SHGC = 0.85 Light transmittance = 89%	Double glazed low emissivity glass U-value = 2.8 W/m²K SHGC = 0.25 Light transmittance = 46%	U-value = 3.3 W/m²K SHGC= 0.25 Light transmittance (min) = 27%

	Base Case	Present case	Total % Reduction
EPI (kWh/ m2 per annum)	605	593	2

(b)

Figure 6 *Energy Efficiency Interventions - Building Envelope (a) Cross Section of Wall and Roof Assemblies. (b) U value Calculations and Energy Performance Index (EPI).*

9.0 LIVE CASE STUDY (CLIMATE: MODERATE)

9.1 Park Turquoise (Location: Wakad, Pune)

Turquoise is Apartment Flats of 2 bhk (1150 sq. ft), 2.5 bhk (1330 sq. ft), 3 bhk (1550 sq .ft).
A Park Turquoise is the luxurious 70-acre township boasting of ample landscaped and open areas.

(a)

(b)

Figure 7 *(a) Layout of Live Case Study (b) Typical Floor Plan of the Building.*

9.2 Construction Techniques

The building envelope has used Autoclaved Aerated concrete blocks instead of conventional bricks. The windows are glazed units with low thermal transmittance. Building Envelop is of AAC blocks with external 1:4 cement and sand plaster and internal gypsum plaster.

U-value calculations for 150mm and 200 mm AAC wall=0.76 w/km² degC and 0.61 w/km² degC.

U-value calculations for 150mm and 230 mm VSBK wall = 1.95 w/km² degC and 1.77 w/km² degC

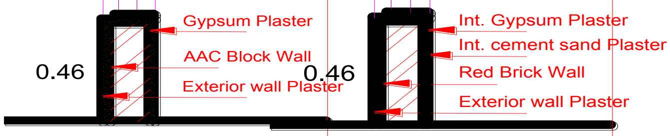


Figure 8 *AAC block Wall Section* *Brick Wall Section*

9.3 Cost Analysis of the Project

All required quantities are refered based on the data collected from the Live Case Study to allow comparision between the two materials.

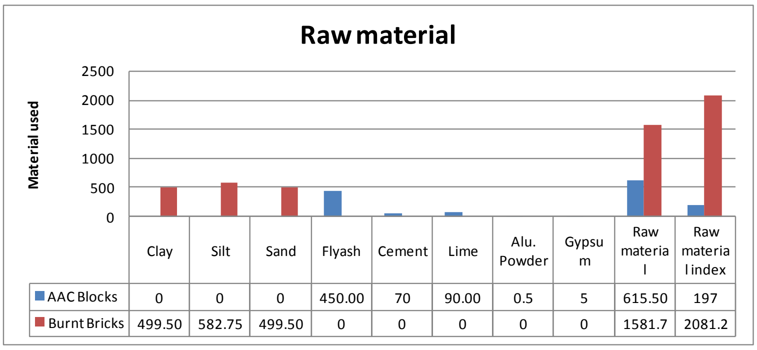
			Aerated Autoclaved Concrete Blocks				Burnt Red Brick		
Description			Qty	AOB	Rate	Value	Qty	Rate	Value
									
Area covered		UOM							
			150 x 250 x 625 mm		Area of bloc	156250	Brick size 230 x 110 x 70		16100
Bricks/Blocks		Nos	4229.96	716942384	86.5	365891.55	44530.58	7.5	333979.37
Cement		Bags	0		0	0	143.39	300	43016.54
Sand		cmt	0.00		0	0.00	1433.88	40	57355.39
mason		Nos	60		350	21000	140	350	49000
helper		Nos	60		200	12000	130	200	26000
Water		2% of co	0		0	0			20000.00
Reinforced Coping		rf	0		0	0	716.94	50	35847.119
Build Fast Plus		kgs	1577.27		380rs/15kg	45600.00	0	0	0
Wastages/Breakages & overheads			3%		411491.55	12344.75	15%	491878.42	73781.76
						456836.29			638980.19
ADDITIONAL COSTS									
Electricity		units	100		6	600	280	6	1680
Manpower for curing- 7days						0	20	200	4000
Labour for sand sieving/brick shifting/reshifting of broken bricks			10		100	1000	15	100	1500
Opportunity Cost + inventory carrying cost- 2%						0	0	2%	
Steel used for structure		kgs	33800.00		50	1690000.00	39000.00	50	1950000.00
Housekeeping			10		100	1000	10	100	1000
						2149436.29	0	0	2597160.19

Table 4 *Comparative cost analysis of Wall Assemblies.*

10.0 LIFE CYCLE IMPACT ASSESSMENT OF AAC BLOCKS AND VSBK BRICKS

Based on the data collected from the live case study, Comparative Analysis is been done between both the materials on various parameters and the results derived from these calculations are as follows:

10.1 Raw Material consumption (per cubic meter of 150 mm thick Non-Loadbearing Wall)



Raw Material Index = (Clay quantity x 2 + Silt x 1 + Sand quantity x 1 + Lime quantity x 1 + Cement quantity x 1 x 1.45 + Fly ash quantity x 0)/5

Source: www.enzenglobal.com/pdf_downloads/strategy_walling.pdf

Figure 9 *Raw Materials in block production and construction of Wall Assemblies.*

10.2 Water Consumption (l/m3 for 150mm Non Loadbearing wall).

	Non-Load bearing walls 150mm thick.				
		Construction		Total water consumption	
	Block production	Unplastered	Plastered	T.W Plastered Wall	T.W Uplatered
AAC Blocks	39655.88	0	200	39855.88	39655.88
Burnt Bricks	44530.58	6219.11	200.00	44730.58	50749.69

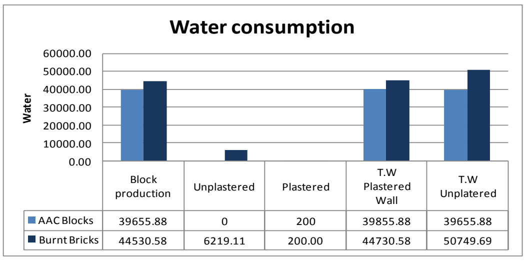
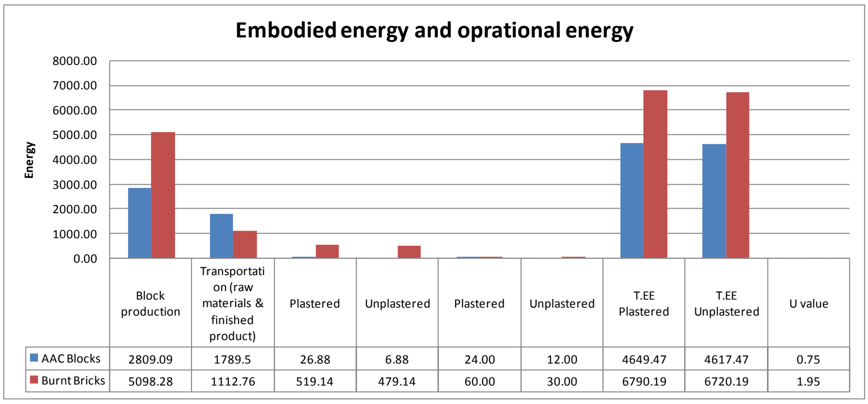


Figure 10 *Water Consumption in Block Production and Construction of Wall Assemblies.*

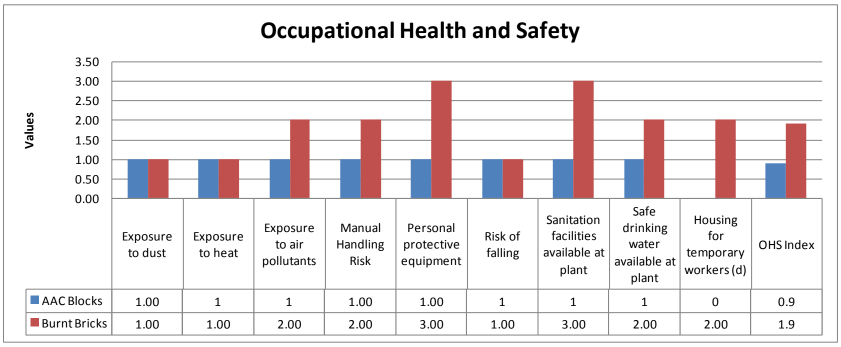
10.3 Energy Consumption (Embodied Energy and Operational Energy of 150 mm Non Loadbearing wall).



About 0.098 tonnes of CO2 are produced per gigajoule of embodied energy = 0.098Kg of CO2 per MJ of embodied energy.

Figure 11 *Embodied energy (MJ/m3) and Operational Energy (W/m2.deg C) in Wall Assemblies.*

10.4 Productivity and OHS (for 150mm Non Loadbearing wall)



Scores for each sub-parameter: High (H) = 3', 'Moderate (M) = 2' and 'Low (L) = 1; Available (A) = 1', 'Inadequate (I) = 2' and 'Not available (NA) = 3, NA=0 for (d), OHS Index = (Sum of scores for each sub-parameter)/9

Figure 12 *Occupational Health and Safety Assessment for masonry Wall Assemblies.*

10.5 Wall cost for 150mm (AAC) and 230mm (VSBK) Non Loadbearing masonry Wall Assemblies:

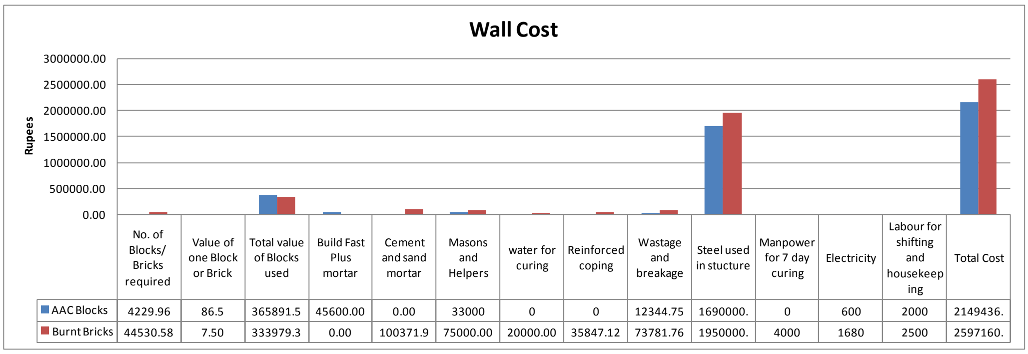


Figure 13 *Total Wall Cost for masonary construction of Wall Assemblies.*

10.6 Emissions:

	Non-Load bearing walls 150mm thick.		
	Production	Construction	Total CO2
	kg of CO2	kg of CO2	kg of CO2
AAC Blocks	275.29	48732.91	49008.21
Burnt Bricks	499.63	65458.52	65958.15

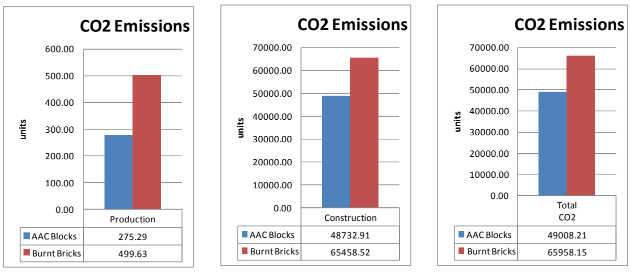
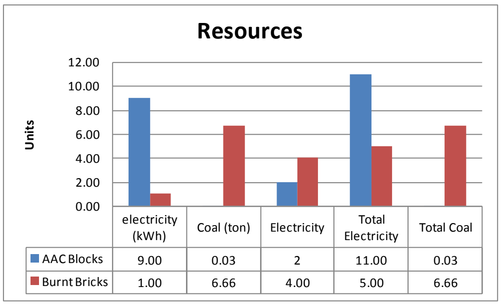


Figure 14 *Emissions related to Wall Assemblies (kg of CO2).*

10.7 Resources used:

	Non-Load bearing walls 150mm thick.							
	Production		Construction	Total water consumption		Emissions		
	electricity (kWh)	Coal (ton)	Electricity	Total Electricity	Total Coal	kg of CO2	kg of CO2	Total CO2
AAC Blocks	9.00	0.03	2	11.00	0.03	0.18073	0.00285	0.18358
Burnt Bricks	1.00	6.66	4.00	5.00	6.66	0.08215	0.6327	0.71485



http://www.victoria.ac.nz/cbpr/documents/pdfs/ee-co2_report_2003.pdf
The total emission factor for electricity is 16.43g CO2 / MJ.
About 0.098 tonnes of CO2 are produced per gigajoule of embodied energy = 0.098Kg of CO2 per MJ of embodied energy.

Figure 15 *Resources used in wall assemblies /cu mt.*

11.0 LIFE CYCLE INTERPRETATIONS

11.1 Overall Comparision

1. It is apparent that masonry units with the least or no clay content (i.e AAC bloc which contains waste material such as Fly Ash) have low impact. Density also influences raw material impact, thus AAC blocks resulting from the aerated nature (approximately 80% air) have lower raw material impact. Larger block size reduces the quantity of mortar wastage on construction site. Additionally, the raw materials that are consumed are generally abundant and found in most geographic regions, allowing them to be locally sourced. Furthermore, much of the raw materials used in AAC production may consist of recycled materials, including copper mine tailings and flyash, a byproduct of coal-fired power plants.

2. AAC blocks use cement in the production process and require curing. However, steam curing under high pressure (autoclaving) results in significantly lower water consumption. Larger block size reduces the quantity of mortar used in construction and thus the water requirement on site. Whereas, Water requires for curing Brick Masonry for 7 days is much large, thus the water consumption increases.

3. Burnt bricks show much higher embodied energy compared to AAC Blocks. The thermal performance of AAC wall assembly is also generally superior to Burnt bricks as reflected in the U-values. AAC blocks wall assembly have the lower U-value due to the porous nature of the material.

4. Burnt brick production is traditionally a labour intensive process. The use of manual labour for moulding therefore results in significantly lower productivity compared to mechanized processes.

Block size also influences construction productivity and a larger block size requires less time and effort for construction. Poor conditions for labour at brick kiln sites are reflected in OHS index compared to AAC. Units producing AAC Blocks are generally located close to large urban areas and do not require labour to live on site during the production period as in the case of Burnt Brick.

5. Cost of AAC block is higher but the overall cost of the construction reduces drastically. Due to the larger block size of AAC masonry reduces the mortar quantity contributing to lower cost for the wall assembly. Also due to its lightweight characteristics the steel consumption reduces by 0.4kg which lower the total cost of construction.

6. CO2 emissions are lower for AAC Production and Wall Assembly compared to Burnt brick Walls and its production.Also, Resource Consunmtion of AAC is lower and thus the CO2 emmissions.

ACKNOWLEDGEMENT

I would like to thank people of AAC block production company Anjali Ventures Ltd., Surat.

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First monitoring results of three straw bale buildings in Belgium

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ABSTRACT

Straw bale use in buildings may be an interesting way to decrease our energy needs and our impact on environment. The present paper describes an experimental set up to monitor three straw bale buildings recently built in Belgium. For each building, results on temperature and relative humidity, inside and outside, are analyzed, as well as internal evolution of temperature and humidity distribution in the walls. The first building is an office building where two finishing are compared. Measurements also provide additional data on CO_2 levels and electric consumption. The two other buildings are dwellings where live one single family. In the first one, a wall in the bedroom and a retaining wall are analyzed. In the second one, a wall in the bedroom and a wall in the bathroom are analyzed. Their hygrothermal behavior is discussed based on simulation results obtained with WUFI Pro and WUFI Plus software. The criterion for the validation of wall behavior is based on water content distribution through the walls. The paper confirms the great potential of this type of building technology and helps to identify how to assess and validate their effective hygrothermal behavior.

Key words: *Straw bale, field measurements, whole building simulation, water content criterion*

INTRODUCTION

Straw bale building techniques are evolving since the XIXth century. Some techniques are still evolving and prefabrication of entire walls has started in Belgium since few years. The present paper presents results based on an experimental setup installed in three straw bale buildings in Belgium. For each of these cases, the straw bale walls were prefabricated in the same factory with the same building technique, except small variations. The wall is built with 46 cm or 36 cm of straw (structured with a timer framed structure), covered on the inside with an 4cm earth plaster and on the outside with a 1.6 cm bracing panel (open to vapor). This walls typology was presented in [Evrard et al., 2012].

The first building is a small office building (approx. 80m²) built in a large industrial hall in Franière. It is thus protected from rain and direct sun. The walls are built with 46 cm of straw. Preliminary simulation results were presented in [Evrard, 2013]. As the building is occupied since September 2013, almost 9 months of monitoring can be analyzed.

The second building is a family house (approx. 225 m²). The monitoring also started in September 2013, but because of undesired power supply failure, only less than 5 months of data can be analyzed. Two different walls are compared, both built with 46 cm of straw. One is facing west and inside environment is a bedroom; the other is a retaining wall in the entrance hall.

The third building is also a family house (approx. 120 m²) built in an urban context in Uccle. It has an attached house on one side. The monitoring started in November 2013 and around 7 months of measurements were thus analyzed. The walls are built with 36 cm of straw in this case. As in the other house, two different walls are compared. One is facing north and inside environment is a bathroom; the other is facing south and inside environment is a bedroom.

METHODOLOGY

The main objective of the monitoring setup presented in this paper is to enable the calibration of numerical simulations and to validate the performances of straw bale walls. It was thus necessary to gather complete climate data for each building (having a different location). For the three buildings, outside temperature and humidity was measured. Sun radiation was measured for the two family houses (west for the first one and south for the second one). Rain load was only measured for west wall in Tongrinne (second building). In addition, temperature and humidity of inside environment of the three buildings was measured, as well as temperature and humidity at different places through the wall. In this first building, complementary sensors were installed to measure CO_2 concentration, windows and doors openings, as well as a webcam to be able to assess occupation. Electrical consumption of monitored room is also measured.

All measures of temperature and humidity were made with the sensors Sensirion SHT75 (except surface temperature made with PT100). A special tube containing a chain of sensors was developed to monitor the temperature and humidity inside the wall, at specific positions. In the two first buildings, 5 sensors are respectively positioned at 2cm (under earth plaster), 11cm (first quarter in straw), 22cm (middle position in straw), 33cm (last quarter in straw) and 44cm (under bracing panel) from inside surface. In the last building, two chains of sensors were used, each with 4 sensors, respectively positioned at 2cm (under earth plaster), 11cm (first third in straw), 22cm (second third in straw) and 33cm (under bracing panel) and at 1cm, 12cm, 23cm and 34cm from inside surface. CO_2 concentration is measured with Gascard NG (3000ppm) sensor. All sensors are connected to a data logger Campbell CR1000 and sent by Internet on a dedicated sever. The data are processed with Microsoft Excel software to allow their use and comparison with numerical simulations. Simulations at wall level are achieved with WUFI Pro 5.2 software and WUFI Plus 2.1 software was used at the building level.

RESULTS

Building n°1: Small office building in Franière

Two different earth plasters on inside surface are compared. For each plaster, three chains of sensors were installed (high, medium and low height). Temperature and humidity evolution are similar for all of these cases, only small variation were observed. Temperature under inner plaster follows very closely the temperature of inside air, and temperature under the bracing panel follows approximately the temperature of outside air (in the hall). The difference is due to the thermal inertia of earth plaster (discussed in [Evrard, 2013]).

As shown in Figure 1 (left), outside temperature (in the hall) was almost never under 0°C. Inside temperature of monitored room falls sometimes under 12°C (6 times between end of November and beginning of February) and do not reach 20°C every working days even if the company installed three simple halogen lamp (400W) to heat the building (one in monitored room) end of November. The lamps are turned on in the morning (between 6am and 9am) and turn off at the end of the day (between 6pm and 8pm). As Figure 1 (right) shows, the occupancy is not regular and, sometimes, nobody is working in the office (i.e. end of December).

Figure 2 (left) presents the data collected in the straw bale for the wall with the plaster n°2, at an approximate height of 1m50 (medium height). It shows the evolution of relative humidity at the most humid point of the wall in winter, i.e. 1cm under the outer bracing panel, as well as the evolution of relative humidity at the driest point of the straw bale in winter, i.e. just under inner earth plaster. It appears that the relative humidity is always under 86% under the bracing panel. According to the sorption curve of straw bales measured in the laboratory, at this humidity, water content is around 16% of mass. Results obtained for plaster n°1 are relevant in this paper. Despite current regulation, no ventilation was installed. Figure 2 (right) shows the evolution of CO_2 concentration in monitored room.

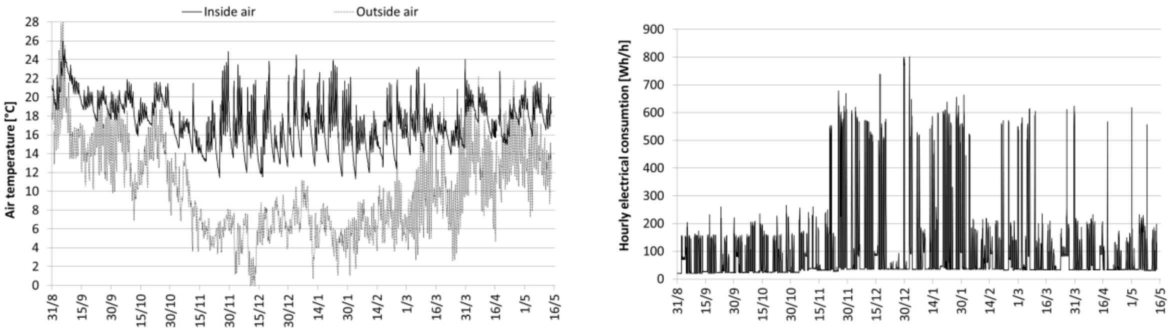


Figure 1 (left) inside and outside air temperature of monitored room in Franière (right) electric consumption of monitored room in Franière.

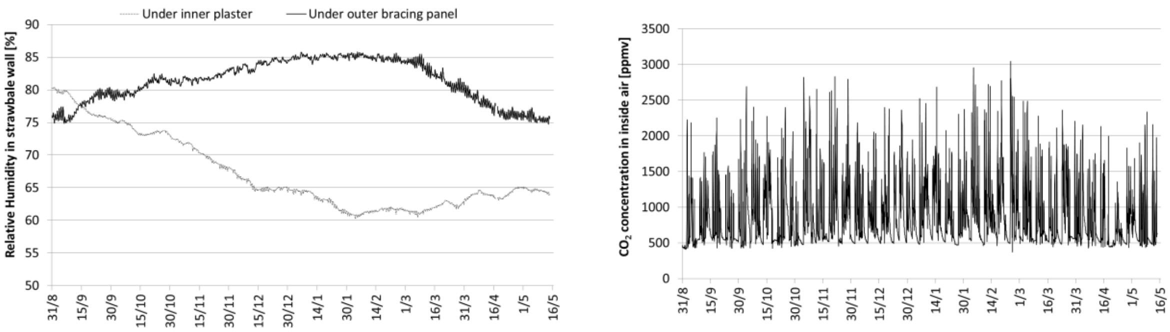


Figure 2 (left) relative humidity under inner plaster and under outer bracing panel of the wall with plaster n°2 in monitored room in Franière (right) CO_2 concentration of inside air in monitored room in Franière.

Building n°2: Family house in Tongrinne

The monitoring of this building started in September 2013, but because of undesired power supply failure, only less than 5 months of data can be analyzed. Two different walls are compared, both built with 46 cm of straw. One is facing west and inside environment is a bedroom; the other is a retaining wall in the entrance hall.

West wall is submitted to driving rain. A water-repellent render system (board, mineral under layer and finishing) was applied on outer surface. Figure 3 shows cumulative rain quantity and sun radiation for this wall, as well as relative humidity through the straw bale.

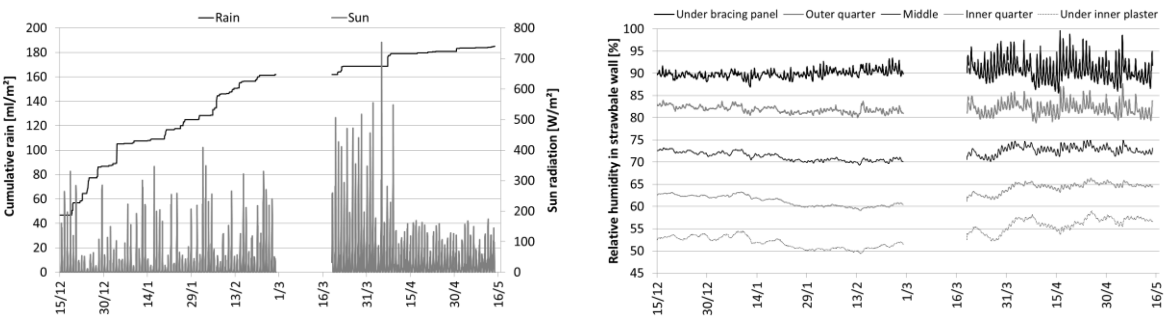
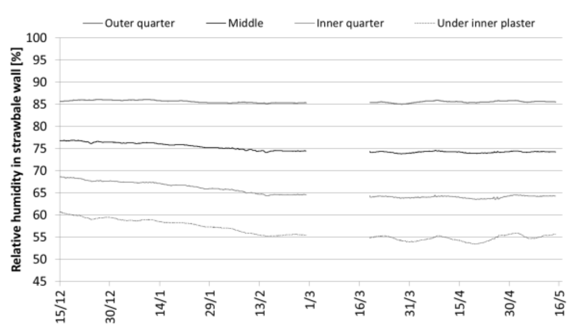


Figure 3 (left) cumulative rain quantity and sun radiation of vertical west wall surface in Tongrinne (right) relative humidity through the straw bale of west wall monitored in Tongrinne.

The other wall monitored in Building n°2 is a retaining wall. Inside environment is the entrance hall of the house. Outside environment is in the earth. A water barrier was installed again outer bracing panel, avoiding water to penetrate the wall, but preventing also vapor to transfer out of the wall on this side. Figure 4 (left) shows relative humidity through the straw bale in this wall (the sensor under the bracing panel do not send any information).



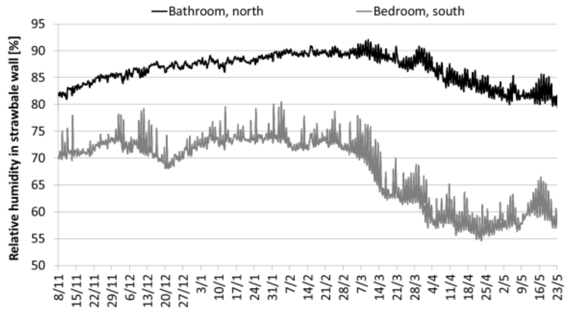


Figure 4 (left) relative humidity through the straw bale of retaining wall monitored in Tongrinne (right) relative humidity under bracing panel of north wall in the bathroom and south wall in the bedroom in Uccle.

Building n°3: Family house in Uccle

The monitoring of this family house started in November 2013 and around 7 months of measurements could thus be analyzed. As in previous house, two different walls are compared, both built with only 36 cm of straw in this case. The first wall is facing north and inside environment is a bathroom; the other is facing south and inside environment is a bedroom. Figure 4 (right) shows relative humidity under bracing panel (the most humid position in the walls) for both walls.

DISCUSSION

Building n°1: Small office building in Franière

Outside temperature and relative humidity from measurements, as well as heating input of electric power released in the room, where used as input in a WUFI Plus simulation (hygrothermal building zone analysis). All necessary material data were gathered during previous step of aPROpaille research. Main parameters are presented in [Evrard, 2013] (exterior wall type “S”). Occupation profile (one man working from 9am to 6pm on week days, with a break between 1pm and 2pm) did not take into account the lightings and the computer, as they are considered in the heating input of the room. Other inputs of the simulation represent real conditions of the unventilated office. A natural ventilation through door and window of 1vol/h between 9am and 10am and between 1pm and 2pm is considered together with a constant infiltration rate of 0.024 vol/h (equivalent to n_{50} = 0.6 vol/h, even if there was no blower door test). This case is thus similar to case S-2 of preliminary simulations presented in [Evrard, 2013].

As illustrated in Figure 5 (left), inside temperature resulting from simulation follows the same trend that measured values. Daily maximum temperature is quite close, but minimum temperature (i.e. after each week-end) is lower in reality. This difference can be due to the hypothesis on ventilation rate and occupation profile. The company should install an adapted heating system to reach comfortable temperature during working days.

Figure 5 (right) shows the evolution of relative humidity at the most humid point of the straw bale in winter, i.e. 1cm under the outer bracing panel, as well as the evolution of relative humidity at the driest point in the straw bale in winter, i.e. just under inner earth plaster. There is a sensible difference between measurements and simulation results in terms of relative humidity in the straw bale. Simulated relative humidity in the straw bale follows the same trend; however, the maximum value under the bracing panel and minimum value under inner plaster are respectively 5% higher and 5% lower in the simulation. This rather small difference is not further analyzed in this paper. As a matter of fact, the relative humidity is always under 90% under the bracing panel. At this humidity, water content of the straw bale is under 20% of mass. According to [Wihan, 2007], no decomposition will occur under a water content of 25% in mass and a degradation of 0,009% a day appears when water content of straw is between 25% and 39% of mass. This analysis depends on the sorption curve of the straw bale and on organic decomposition rate (the values may depend on the density of the straw bale, the type of plant…).

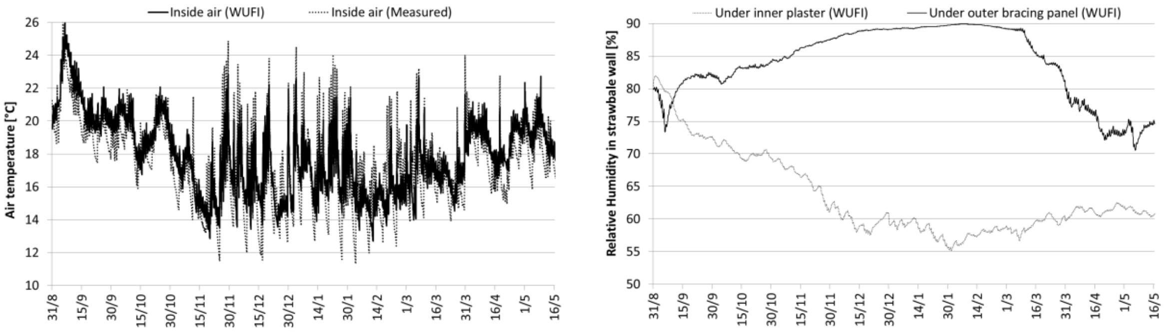


Figure 5 (left) inside air temperature in Franière, simulated with WUFI Plus software (right) relative humidity under inner plaster and under outer bracing panel in the straw bale with plaster n°2 in Franière, simulated with WUFI Plus software.

One last remark can be made on the evolution of CO_2 concentration in the simulation. As we defined a constant occupation every week-days (with a break at noon) and almost no ventilation, CO_2 concentration rises every week-days until around 3700ppmv (vs. maximum value measured is 3000ppmv). A ventilation system (around 30m³/pers) can be used to reduce CO_2 concentration under 1000ppmv (Belgian regulation NBN EN 1377-2007). A precise occupation profile could be assessed based on measured CO_2 concentration, but this goes beyond the scope of this paper because it would need, in addition, a complementary analysis of ventilation rate.

Building n°2: Familly house in Tongrinne

Outside and inside temperature and humidity, as well as sun exposure and rain load on west wall were used to run WUFI Pro simulations (1D hygrothermal analysis). Missing data between the 28th of February and the 19th of March were filled with data measured between the 7th of February and the 26th of February for continuity of the climate file. Material data were gathered in previous step of the research (see [Evrard, 2013]).

For the water-repellent render system, density, thermal conductivity and vapor diffusion resistance factor of each layer were collected from producers. Other parameters (porosity, specific heat capacity, sorption curve…) correspond to a "Cement Plaster" in WUFI database, except liquid absorption coefficient (A-value). Finishing mattering is announced to be "water repellent" and A-value is set to 0.0017 kg/m²s$^{-1/2}$. The producer indicates that sd-value of this layer is higher than 0.5m. As layer must be minimum 1mm in WUFI Pro, the vapor diffusion resistance factor of this layer is set to μ=500 (500*0.001m=0.5m). A-value of the board and render are set to 0.0083 kg/m²s$^{-1/2}$ corresponding to the worst value in class II of standard NF EN 1062-1 (W2 announcer by producer).

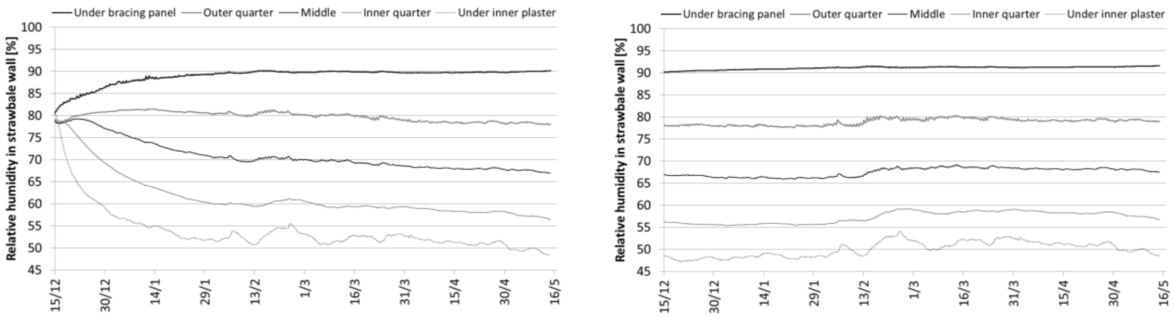


Figure 6 (left) relative humidity through the straw bale wall orientated to the west in Tongrinne (first period), simulated with WUFI Pro software (right) relative humidity through the straw bale wall orientated to the west in Tongrinne (second period), simulated with WUFI Pro software.

Figure 6 (left) shows the simulated relative humidity through the straw bale wall of the west wall in Tongrinne. Initial humidity of the straw bale was set to 80% (constant through component). The two first months are thus very different form measured value, but from the 15th February until 15th of May, the results are in very good agreement. The main difference is the higher daily amplitude of the variations of relative humidity (especially close to outside) in the measurements, but average values are similar.

Measured values are very often over 91.4% of relative humidity, corresponding to a water content over 25% in mass. Simulated values rise until 90% of relative humidity and seem to continue to rises as time passes. A second period (with the same climate file) was simulated starting with water content profile obtained at the end of the first period (which was rather rainy). Figure 6 (right) shows that an accumulation of humidity can be observed. The maximum water content during second period is over 25% of mass. An explanation of this problematic behavior is the rather high vapor permeability of finishing layer (sd = 0.5m or more). If this layer has a sd-value of 0.05m, the simulation shows no moisture accumulation and relative humidity under the bracing panel stays under 90%.

A this point, it has to be noticed, that equivalent simulations, using “test reference year” (TRY) in Uccle (50 km from Tongrinne) for outside climate and EN15026 standard for inside, do not reveal any problem in the wall. The relative humidity of the straw under the bracing panel gets close to 90% but decrease after the month of June. No accumulation is observed and no degradation should occur. It is thus too early to conclude that organic degradation will occur in the straw over time as a significant decrease of relative humidity at this specific place may be observed in following months (summer period).

To simulate the retaining wall, only inside climate was used as an input for simulation. For outside climate (in the earth), a sinus variation of temperature around 15°C and with amplitude of 3°C (maximum on the 1st of August) and a constant humidity of 99% are chosen. No absorption of water is allowed in the wall and a 1mm layer with very low vapor permeability is considered (sd=1500m). As in previous simulation, initial humidity of the straw bale was set to 80% (constant through component). Figure 7 (left) shows that there is a difference of around 5% of relative humidity between simulated results and measurements at the end of the first period. Under the bracing panel, the relative humidity seems to decrease after the 15th of April (the sensor at this position does not send any information). At the opposite, relative humidity under inner plaster seems to increase after end of March. When repeating simulating a second period, starting with water content profile obtained at the end of the first period, a significant decrease in straw bale humidity can be observed, as shown in Figure 7 (right). The results are similar when using a usual inside climate (“normal moisture load”) based on standard EN15026 with TRY reference climate in Uccle (50km from Tongrinne): the maximum relative humidity under the bracing panel during the third year is 83% (86% with “high moisture load”), with no accumulation. Before drawing any conclusion, positive results from simulations suggest to wait to have a longer measuring period to further discuss measured values.

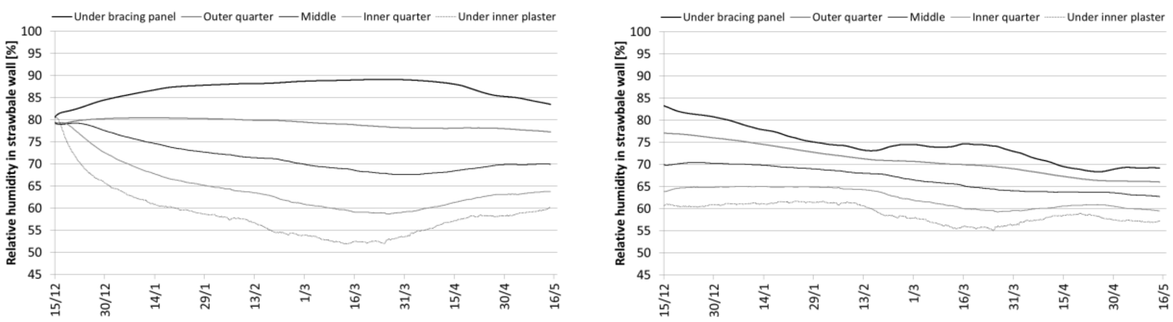


Figure 7 (left) relative humidity through the straw bale retaining wall in Tongrinne (first period), simulated with WUFI Pro software (right) relative humidity through the straw bale retaining wall in Tongrinne (second period), simulated with WUFI Pro software.

Building n°3: Familly house in Uccle

Outside and inside temperature and humidity (in both rooms), as well as sun exposure on south wall were used to run WUFI Pro simulations (1D hygrothermal analysis). Material data were gathered in previous step of the research (see [Evrard, 2013]). A render on outside surface (2cm) was applied on both walls on a wood-cement board (2.5cm) fixed on a wood structure (unventilated air layer of 3cm) directly on bracing panel. The total complementary sd-value of those three layers is supposed to be around 30cm. Rain absorption of outside surface is neglected in the simulations (no rain load was measured in Uccle and the render is supposed to be water-repellent). Inner finnishing is also neglected for both walls (thin lime plaster).

Figure 8 shows that there is a significant difference of relative humidity under the bracing panel between measurements and simulation results. In the bedroom, simulation results are 10% to 15% higher during the two first months and after four month. In the bathroom, results are similar at the beginning and at the end of the period, but diverge between the second and the seventh months (difference up to 15%). At this point, these simulation results cannot be used because they may not be relevant. This might be due to hypothesis on rain, or on material parameters (outside render and inner plaster). Further research is needed. However, it has to be noticed that measured values are fine in the bedroom (relative humidity of the straw under the bracing panel is always under 80%) and, for the bathroom, they exceed 91.4% of relative humidity under the bracing panel, only during few days.

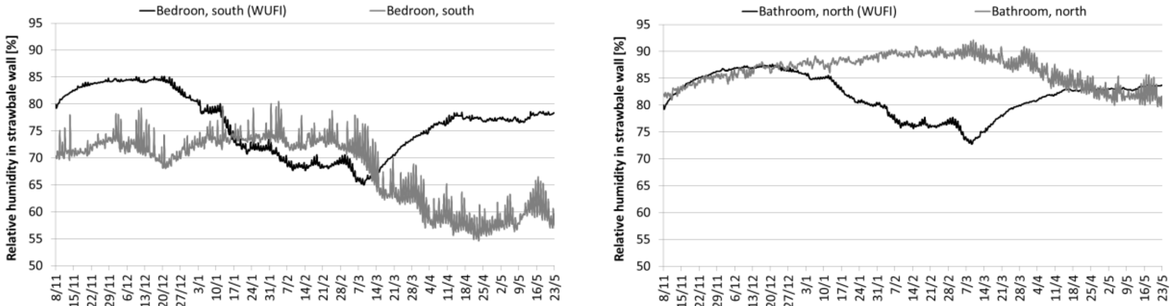


Figure 8 (left) relative humidity under bracing panel of south wall in the bedroom in Uccle, simulated with WUFI Plus software (right) relative humidity under bracing panel of north wall in the bathroom in Uccle, simulated with WUFI Plus software.

CONCLUSION

The paper presents the first analysis of the data collected in three straw bale buildings in Belgium: one office and two family houses. All data are collected on a dedicated server and are analyzed after a processing with Microsoft Excel software. Based on [Wihan, 2007] and [Evrard et al., 2012], validation of wall behavior focusses on the humidity in the straw bale. Relative humidity of straw should not exceed 91.4% (corresponding to a water content of 25% of mass). The most humid place in the walls (if no undesired source of humidity exists), is located few centimeters under the outer bracing panel. Results at this place are discussed based on simulation results, either with WUFI Pro (using indoor and outdoor climate from field measurements) or with WUFI Plus software (when data on occupation and heating load are also available).

The office building in Franière (Building n°1) was built in an industrial hall and is not submitted to rain or sun. Therefore, the analysis of occupation and heat load was simplified. All data were analyzed with WUFI Plus software. The behavior of all walls was validated (no decomposition will occur). A relatively good agreement between measured relative humidity and simulation results were observed (i.e. less than 5%). Inside temperature from simulation follows the same trend as measured values, but do not decrease as fast at night and during the week-end. Additional research on occupation profile and ventilation rate should help to calibrated more precisely the simulations (e.g. in terms of CO2 concentration of inside environment).

In Tongrinne (Building n°2), west wall seems to have a problematic behavior as the relative humidity in the straw under the bracing panel is often higher than 91.4%. In addition, simulation results indicate that the wall may have a moisture accumulation problem. However, other simulations using test reference year (TRY) in Belgium did not confirm this result, and a new analysis of monitored data should take place after summer period. This uncertainty may come from unknown material parameters of outer render added on prefabricated straw bale walls.

The second wall in Tonginne is a retaining wall. Unfortunately, one sensor (under bracing panel) does not send any data. The simulation is rather positive as it shows that on a longer period, the humidity of the wall should decrease under critical value. A special attention will be given to this wall in the future as it is normally avoid designing retaining wall with straw bales.

In Building n°3 (in Uccle), simulation results did not fit measurements. Again, this could be due to unknown material parameters of outer render added on prefabricated straw bale walls. In addition, west wall is submitted to driving rain, but no rain measurement was implemented in this case. Further analysis of this building is needed to validate hygrothermal behavior of the walls. Nevertheless, measured values are not considered to be critical (only few days over 91.4%) in this case.

If many data can still be not explored, the monitoring implemented in three straw bale buildings can already confirms that it is possible to design and validate straw bale walls based on a single quantified criteria: moisture content of straw few centimeters under the bracing panel. More research is needed to understand the link between critical moisture content and other parameters (density of the straw bale, type of plant, forming process of the bale…).

In the meantime, straw bale walls can be trusted to design high efficiency house and to offer comfortable and sustainable living places.

ACKNOWLEDGMENTS

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Session 8B : Innovative construction technology

PLEA2014: Day 3, Thursday, December 18, 2014
14:10 - 15:50, Compassion - Knowledge Consortium of Gujarat

Microclimatic Effects of Individual Trees with Their Transpiration

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ABSTRACT

This paper quantifies whole-tree transpiration rates for urban tree species using a weighing lysimeter and identifies the microclimatic cooling effect of the individual trees. A novel weighing lysimeter was developed for measuring the whole-tree transpiration rate with a high degree of accuracy. Eleven urban tree species were selected and their whole-tree transpiration rates were measured during the summer season. The daily transpiration amounts of the selected trees, whose heights ranged from 3 m to 7 m, varied from 10 kg to 30 kg under clear skies and water supply conditions. The ratio of the daily transpiration amount to potential evaporation was 0.6 $\pm$ *0.3 when using the standard of crown projection area. The vapor diffusion conductance peak appeared during the morning, and that of transpiration appeared in the afternoon under clear sky conditions. The peak values of transpiration rates for tree species that showed large transpiration amounts were over 3 kg/h. This value is equivalent to more than 2 kW of latent heat flux. The peak values of transpiration rate and vapor diffusion conductance decreased as soil water content decreased, and the latent heat flux decreased from 2 kW to 0.7 kW by the water stress of the tree. This means that the cooling effect decreased to one third. The relationship between vapor diffusion conductance and soil water content was hysteretic when the soil water content was varied by the water-supply stop test. A decrease in vapor diffusion conductance appeared two days after the water supply was terminated, and it recovered three days after water supply resumption.*

INTRODUCTION

In order to understand the microclimatic cooling effects of trees in urban spaces, it is important to quantify their transpiration rates and latent heat fluxes, taking into account species characteristics and soil water content. In previous studies that dealt with the transpiration of trees, transpiration characteristics were reported and compared among different tree species and sizes (Chen et al. 2011; Peters et al. 2010). Whole-tree transpiration rates in these studies were mainly estimated by sap flow measurement using the Granier method (Köstner et al. 1998), or via transpiration measurements for several leaves using the porometer method (DeRocher et al. 1995). However, these methods provide an indirect estimation of whole-tree transpiration, and it has been difficult to obtain accurate whole-tree transpiration rates. Therefore, differences in whole-tree transpiration rates between differing species and tree sizes are uncertain, as is the averaged value of the transpiration rate among tree species in urban environments.

Whole-tree transpiration measurement data are important and useful for assessing the environmental performance of built environments, including urban greening, as well as for the selection of input and validation data for microclimate simulations. In Japan, the Japanese government has

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promoted the use of CASBEE (Comprehensive Assessment System for Built Environmental Efficiency) (Murakami et al. 2014), which has been developed by the Japan GreenBuild Council (JaGBC) and the Japan Sustainable Building Consortium, for use in building developments by construction companies, design offices, and real-estate developers. CASBEE-HI (Heat Island) is a component of CASBEE, and is focused on the evaluation and promotion of countermeasures that can mitigate the urban heat island effect. In CASBEE-HI, the cooling effect of tree transpiration is simply evaluated using data from forests and trees under different conditions, therefore, the applicability of the data and the reliability of the evaluation criteria have been discussed in both academic fields and in terms of practical use (Teshirogi and Koshimizu 2011). This discussion has been spurred by a lack of reliable and applicable data for urban trees and the above issue is indicative of the importance of measurement data related to whole-tree transpiration.

This paper reports a novel attempt to measure whole-tree transpiration rates for urban tree species by use of a large weighing lysimeter, and compares the transpiration rates and cooling effects among these tree species. In addition, the effect of soil water content on the transpiration rate is examined for *Zelkova serrate* during the summer season. The obtained data will contribute to the creation of a fundamental database for heat island countermeasures using urban trees.

METHODS

Materials and Site

Previous studies of plant physiology have discussed the effects of leaf life-span (evergreen or deciduous), xylem porosity, trunk diameter (sapwood area) and tree height on transpiration characteristics. The leaf life-span correlates with photosynthetic capability and xylem porosity, while trunk diameter and tree height affect the water supply capability to the leaves. In the present study, we selected 11 tree species for the comparison experiment, taking into account leaf life-span (evergreen and deciduous) and xylem porosity. Table 1 shows the selected trees and their characteristics. The tree heights varied from 3 m to 7 m in the year 2012, during which many of the measurements were conducted. These trees were planted in individual large planters with areas of 1 m^2 and depths of 0.6 m.

The measurement site is an experimental field with an area of 8800 m^2 in Miyoshi city of Aichi prefecture, Japan. The positions of the trees are shown in Figure 1 and Figure 2. The distances between the trees were greater than 4 m, so that each tree could easily receive solar radiation and air flow. This planting condition was considered for application of the experimental results to urban environmental conditions.

Table 1. Trees characteristics and daily transpiration values

	Z. s. 2010	Z. s. 2012	Q. m. 2012	Q. m. 2013	S. j.	C. × y.	G. b.	Q. s.	C. c.	B. j.	M. s.	Q. a.	M. k.
Leaf Life-span [month]	8	8	36	36	8	8	8	8	12	8	8	8	8
Xylem Porosity	Ring-porous	Ring	Diffuse	Diffuse	Diffuse	Diffuse	Tracheid	Ring	Diffuse	Diffuse	Diffuse	Ring	Diffuse
Crown Projection Area (8 points) [m^2]	5.1	9.2	3.3	-	6.6	7.8	4.5	7.3	3.6	6.9	1.5	7.5	6.1
Tree Height [m]	6.4	6.4	5.5	-	4.4	5.5	5.4	5.8	4.7	4.5	3	6.7	4.1
Basal Diameter [cm]	-	-	12	12	11	14	13	14	13	12	6	11	13
Trunk Diameter [cm] (below the lowest living branch)	10	11	10	10	9	10	10	9	9	9	5	8	8
Daily Transpiration [kg/tree/d]	28.1	25	6.8	26.8	10.9	13.7	16.3	32.2	28.1	22.2	11.5	25.1	20.9

Figure 1. Experimental site and trees

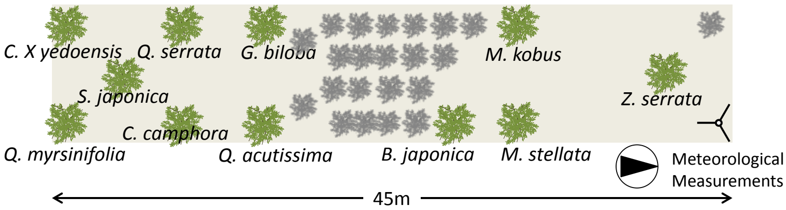

Figure2. Layout of trees

Measurement devices and methods

Whole-tree Transpiration Rates. In order to accurately measure whole-tree transpiration, weighing lysimeters were developed using weighing load cells (Asawa et al. 2012). Whole-tree transpiration rates were measured by the change in tree weight within the planter. For the long-term measurement of *Zelkova serrate*, a platform weighing machine (Sartorius AG, CAPS4-1500LL-I) was used. The water balance was also measured, including the amount of supply and drainage water. The evaporation from the soil surface was restricted by a cover, and the soil surface was shielded from rain water by a shed. Therefore, the weight change was clearly identified as the transpiration rate. For short-term measurements of the other tree species, S-type load cells (Minebea, U3S1-100K~5T-NS) were used. The planter was suspended by the load cells at three points, and the weight change was measured (Figure 3). In outdoor experiments, wind can be the source of noise and error in weighing measurements. In the previous study, we showed that this method removed the effects of wind by allowing the selection of data recorded when the fluctuation of weight values were small and stable in a short time span, and we confirmed that the measurement error of whole-tree transpiration rates was within 100 g/h when wind velocity was below 1.5 m/s (Asawa et al. 2012).

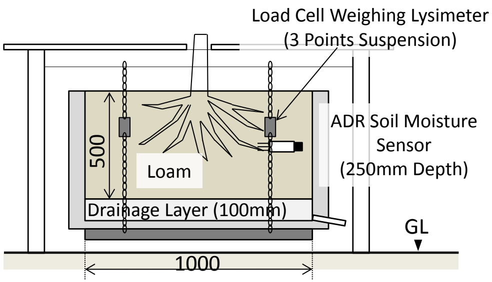

Figure 3. Weighing lysimeter for whole-tree transpiration measurements (Short term measurement)

Table 2. Measurement devices

Weight (Tree+Soil+Planter) 1) *Zelkova serrata* 2) Other species	1) Platform weighing machine (Load cell type) CAPS4-1500LL-I (Zartorius AG) 2) S-type load cell U3S1-100K~5T-NS (Minebea)
Soil water content	ADR soil moisture sensor ThetaProbe ML2x (Delta-T)
Air temperature	Aspirated radiation shield YG-43502 (R.M. Young) Platinum resistance thermometer (Pt100)
Relative humidity	Capacitive humidity sensor
Global solar radiation	Pyranometer (Thermopile type) MS-402 (EKO Instruments) 0.3~2.8μm
Wind direction and wind velocity	3D ultrasonic anemometer CYG-81000 (R.M. Young)
Photosynthetic photon flux density	Quantum sensor 0.4~0.7μm LI190 (LI-COR)
Precipitation	Tipping bucket type rain gauges TE525MM (Campbell Scientific Inc.)

Meteorological Data and Water Balance. The meteorological data was measured at the northern part of the experimental field. The measurement devices are shown in Table 2. The measurements consisted of global solar radiation, air temperature, relative humidity, three-dimensional wind direction and velocity, and photosynthetic photon flux density. The measurement height for wind direction and velocity was 4 m. Soil water content was measured by an ADR soil moisture sensor with a ThetaProbe. The water supply and water drainage volumes were measured by tipping bucket-type rain gauges. The water supply volume was fully controlled and the water supply was automatically implemented at midnight on each day.

Measurement Periods and Conditions. The transpiration rate of *Zelkova serrate* was measured continuously from July 2010 to the end of 2013. During the water stress test for *Zelkova serrate*, the water supply was stopped for several days. The transpiration rates of the other ten species were measured for about two weeks in the summer of 2012 and 2013, and three species were measured at a time. The results obtained during clear sky days were selected and used for the analysis, so as to select data gathered under identical conditions.

Estimation of Vapor Conductance. The transpiration from a leaf can be described as a vapor diffusion process, and expressed in an equation as the product of vapor pressure deficit and vapor diffusion conductance. The physiological characteristics of transpiration, including stomatal control, find expression in the vapor diffusion conductance. The vapor pressure deficit is the difference between the saturated vapor pressure of the leaf and atmospheric vapor pressure. In this study, whole-tree vapor diffusion conductance is estimated by Eq. (1) using measured whole-tree transpiration rates and vapor pressure deficit. Eq. (2) shows the components of vapor diffusion conductance.

$$G = ET / W \tag{1}$$

$$G = 1 / (r_a + r_s) = g_a \cdot g_s / (g_a + g_s) \tag{2}$$

RESULTS AND DISCUSSION

Comparison of Transpiration Rates among Urban Tree Species

Daily Transpiration Amount. The measured daily transpiration amounts are shown in Table 1. For *Quercus mirsinifolia*, the transpiration rate was measured in both 2012 and 2013, because the tree had been moved from an area enclosed by other trees to an open space before the 2012 measurement. The tree species that showed the largest daily transpiration amounts were *Zelkova serrata* (2010), *Quercus serrata* and *Cinnamomum camphora*, the values of which were approximately 30 kg. The next largest amounts were observed in *Quercus mirsinifolia* (2013), *Quercus acutissima* and *Zelkova serrata* (2012), which showed values of approximately 25 kg. In contrast, the smallest transpiration amounts were observed in *Quercus mirsinifolia* (2012), *Styrax japonica* and *Magnolia sellata*, with these species showing values of approximately 10 kg. The transpiration amounts of *Zelkova serrata* and *Quercus mirsinifolia* largely varied from year to year. Although the leaf area of *Zelkova serrata* increased from 15.4 m^2 in 2010 to 28.9 m^2 in 2012, the transpiration amount slightly decreased. Water conductance in trunks and branches are restricted by the area of the roots and sapwood, therefore, the maximum transpiration value of *Zelkova serrata* was 30 kg/day under the conditions of planter size (1 m × 1 m × 0.6 m) and trunk diameter (0.1 m). In contrast, for *Quercus mirsinifolia*, although the crown shape and leaf area did not change considerably from 2012 to 2013, the transpiration amount increased by a factor of three. These findings indicate that photosynthetic ability largely increased due to the change in tree location from an enclosed space to an open space, which resulted in changes in the surrounding conditions.

Diurnal Changes of transpiration rate and latent heat flux. Figure 4 shows diurnal variations in transpiration rate, vapor diffusion conductance and latent heat flux for 11 tree species. A peak in transpiration rate appeared in the afternoon for tree species that showed large transpiration amounts. In contrast, for trees that displayed small transpiration amounts, the peak appeared in the morning. The peak values for *Zelkova serrata* (2010), Q*uercus mirsinifolia* (2013), *Quercus serrata* and *Cinnamomum camphora* were over 3 kg/h. This value is equivalent to more than 2 kW and 400 W/m^2 of latent heat flux. A peak in transpiration rate for these trees, whose heights ranged from 3 m to 7 m, varied from 1.3 kg to 3.6 kg. These values are equivalent to the range from 880 W to 2400 W for latent heat flux. Therefore the difference in cooling effect was approximately 1500 W between these trees. Peaks in vapor conductance appeared in the morning and the values decreased into the afternoon for all species. This result indicates that the stomata were closed in the afternoon, during which solar radiation and vapor pressure deficit were high, so as to minimize the water deficit. The species with small transpiration amounts were more sensitive to the water deficit than those exhibiting large transpiration amounts.

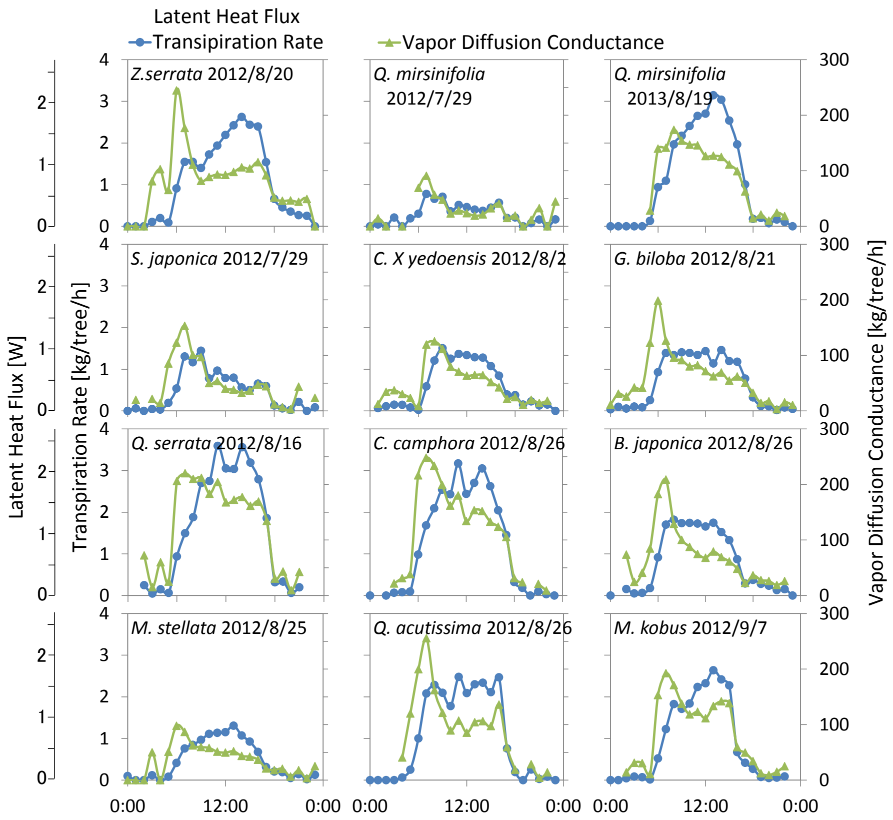

Figure 4. Measurements of whole-tree transpiration and vapor diffusion conductance, and estimations of latent heat flux

Analysis of Dayly Transpiration Amount Based on Potential Evaporation

Priestley–Taylor Equation. Transpiration is influenced by meteorological conditions, so this section analyzes and compares the transpiration characteristics among these tree species based on the standard of potential evaporation (ET_{pot}). ET_{pot} is estimated by the Priestley–Taylor equation (Eq.(3)) (Ptiestley and Taylor 1972).

$$\lambda E = 1.26 \frac{s}{s+\gamma}(R_n - G) \tag{3}$$

The Priestley–Taylor equation is a semi-empirical model that predicts the evaporation rate of water surfaces based on the heat balance. The coefficient, 1.26, on the right side on the equation was empirically obtained from measurements on water surfaces, on which there was no horizontal advection. The heat conduction, G, was assumed to be negligible in this study.

Creation of a Database of Daily Transpiration Amounts Per Ground Area. Figure 5 shows the ratio of the measured transpiration amount to potential evaporation (ET/ET_{pot}) during clear sky and water supply conditions. In the field of hydrology and meteorology, the crown projection area is generally used as a standard when comparisons are made with potential evaporation. In this study, the area of the planter (1m × 1m) is also used as a standard, as well as the crown projection area.

The average and standard deviation of ET/ET_{pot} was 0.6 ± 0.3, when using the standard of crown projection area. The reason why this averaged value was smaller than 1 is that the stomata restricted transpiration to prevent water loss. This result corresponds to previous measurements made in forests and croplands. Although ET/ET_{pot} is smaller than 1 on average, *Cinnamomum camphora* displayed a value of 1.1 in this experiment. It is considered that the transpiration amount of *Cinnamomum camphora* is large for its crown size, and that the transpiration rate per LAD and leaf area is also high.

The averaged value and standard deviation of ET/ET_{pot} was 2.7 ± 1.1 when using the standard of planter area, and this large value is due to the fact that the transpiration area of the crowns is much larger than the planter area. This result indicates that the planting of tall trees is more effective than the use of water surfaces in urban spaces, because the space under the crown can be used while obtaining the cooling effect.

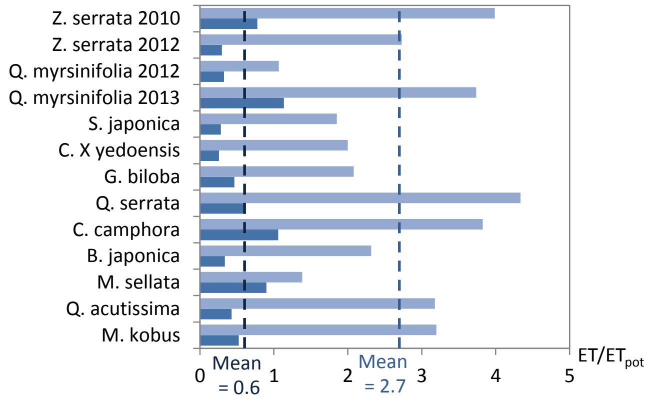

Figure 5. Daily transpiration amount per ground area (ET/ET_{pot}, Clear sky and water supply conditions)

Influence of species and crown features. Figure 6 shows (ET/ET_{pot}) for all tree species when using the standard of planter area. In general, there is a correlation between whole-tree transpiration and leaf area, so it is considered that there is also a correlation between whole-tree transpiration and the crown projection area and basal diameter. However, an obvious correlation could not be confirmed in Figure 6. In future studies, we intend to analyze the effect of LAI (Leaf Area Index) and LAD (Leaf Area Density) on whole-tree transpiration.

Focusing on differences in xylem porosity, *Quercus acutissima*, *Zelkova serrata* and *Quercus serrata*, which are ring-porous and have thick trachea, showed relatively large transpiration amounts. In general, the photosynthetic rate is inversely proportional to leaf life-span, and transpiration and photosynthesis are simultaneously controlled by the stomata. Therefore, we expected a difference in transpiration amounts based on leaf life-span (evergreen or deciduous), but any clear differences were not observed.

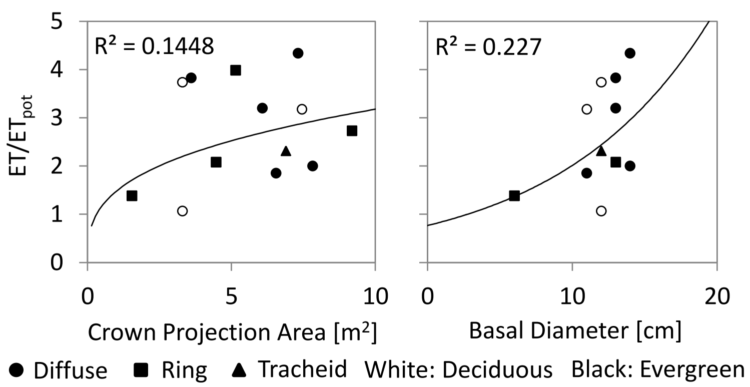

Figure 6. Relationship between daily transpiration amount and tree characteristics

Relationship between Soil Water Content and Transpiration

Transpiration characteristics depend on soil water content. In many urban spaces, planted trees often suffer from water stress, due to insufficient precipitation and water supplies (Kagotani et al. 2013). Figure 7 shows measurements collected during the water stress test, in which the water supply was stopped for three days from August 24 to 26, 2010. The soil water content shown in Figure 7 is the averaged value of five measurements taken at different depths. The transpiration rate and vapor diffusion conductance decreased as soil water content decreased. The peak value of the transpiration rate and vapor conductance decreased to one third and one half, respectively, from August 24 to 26. The pak value of latent heat flux decreased from 2 kW to 0.7 kW by the water stress of the tree. This means that the cooling effect decreased to one third. Although the water supply was resumed early on the morning of August 27, the transpiration rate on the day was almost equal to that observed on August 26. Therefore, transpiration did not recover quickly from water stress.

Figure 8 shows the transition in soil water content and vapor diffusion conductance during the water stress test. The relationship between soil water content and vapor conductance was hysteretic after the water supply was halted and resumed. A decrease in vapor conductance appeared two days after the supply of water was stopped, and it recovered three days after water supply resumption. This finding suggests that soil water content levels should be considered during any evaluation of the cooling effects of trees in urban environments.

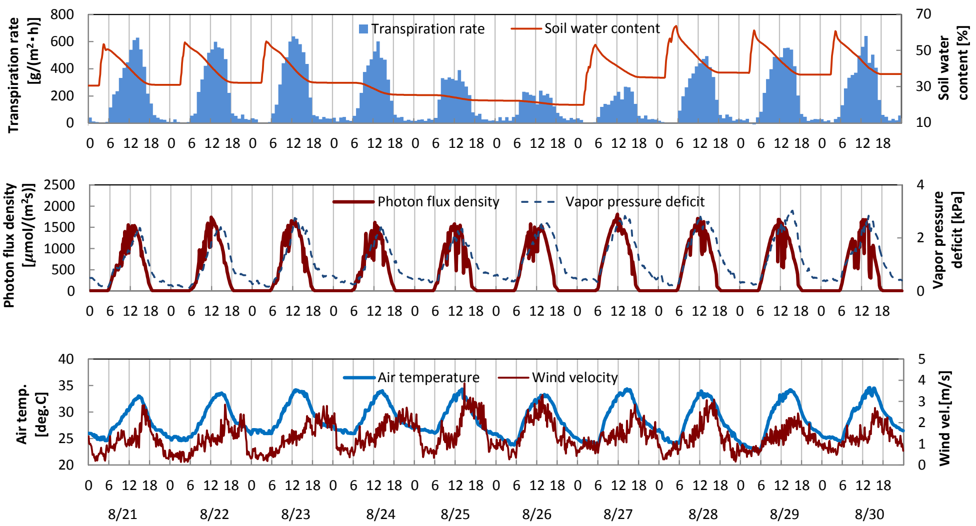

Figure 7. Relationship between transpiration rate and soil water content (*Zelkova serrata*)

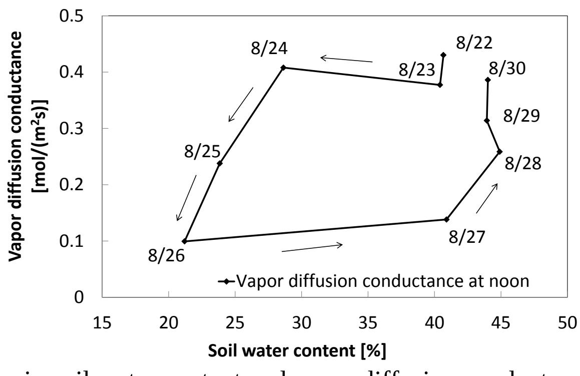

Figure 8. Transition in soil water content and vapor diffusion conductance (*Zelkova serrata*)

CONCLUSIONS

This paper shows the characteristics of whole-tree transpiration rates for urban tree species, using a weighing lysimeter. The daily transpiration amounts of the trees, whose heights ranged from 3 m to 7 m, varied from 10 kg to 30 kg under clear sky and water supply conditions during the summer. The ratio of the daily transpiration amount to potential evaporation was 0.6 $\pm$ 0.3, when using the standard of crown projection area. The vapor diffusion conductance peaks appeared in the morning, and that of transpiration appeared in the afternoon under clear sky conditions. The peak values of the transpiration rate for tree species that displayed large transpiration amounts were over 3 kg/h. This value is equivalent to more than 2 kW and 400 W/m^2 of latent heat flux. A peak in transpiration rate for these trees varied from 1.3

kg to 3.6 kg. These values are equivalent to the range from 880 W to 2400 W for latent heat flux and the difference of 1500 W is regarded as the difference in the cooling effect. The peak values of transpiration rate and vapor diffusion conductance decreased with soil water content. The cooling effect of the tree decreased to one third when the tree was under water stress. The relationship between vapor conductance and soil water content was hysteretic when soil water content was varied by the water-supply stop test. A decrease in vapor diffusion conductance appeared two days following the cessation of the water supply, and it recovered three days after water supply resumption. This observation suggests that soil water content levels should be considered for the evaluation of the cooling effect of trees in urban environments.

ACKNOWLEDGMENTS

We express gratitude to the TOYOTA Motor Corporation, Biotechnology & Afforestation Business Division for their assistance with the experiments.

NOMENCLATURE

ET	=	Whole-tree transpiration rate	[mol/(m^{2}s)]
ET_{pot}	=	Potential evaporation	[mol/(m^{2}s)]
G	=	Vapor diffusion conductance	[mol/(m^{2}s)]
W	=	Vapor pressure deficit	[kPa/kPa]
r_a	=	Boundary layer resistance	[m^{2}s/mol]
r_s	=	Stomatal resistance	[m^{2}s/mol]
g_a	=	Boundary layer conductance	[mol/(m^{2}s)]
g_s	=	Stomatal conductance	[mol/(m^{2}s)]
λ	=	Latent heat of vaporization	[J/mol]
E	=	Evaporation rate	[mol/(m^{2}s)]
s	=	Slope of the saturation vapor pressure-temperature relationship	[K^{-1}]
γ	=	Psychrometric constant	[K^{-1}]
R_n	=	Net radiation	[W/m^2]
G	=	Conductive heat flux into ground	[W/m^2]

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Assessment of the double-skin façade passive thermal buffer effect

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ABSTRACT

Double Skin Façades (DSFs) are becoming increasingly popular architecture for commercial office buildings. Although DSFs are widely accepted to have the capacity to offer significant passive benefits and enable low energy building performance, there remains a paucity of knowledge with regard to their operation. Identification of the most determinant architectural parameters of DSFs is the focus of ongoing research. This paper presents an experimental and simulation study of a DSF installed on a commercial building in Dublin, Ireland. The DSF is south facing and acts to buffer the building from winter heat losses, but risks enhancing over-heating on sunny days. The façade is extensively monitored during winter months. Computational Fluid Dynamic (CFD) models are used to simulate the convective operation of the DSF. This research concludes DSFs as suited for passive, low energy architecture in temperature climates such as Ireland but identifies issues requiring attention in DSF design.

INTRODUCTION

A Double Skin Façade (DSF) or Multi Skin Façade (MSF) is generally composed of a glazed curtain offset from the line of the building envelope (Figure 1). DSFs have continued to increase in popularity, particularly in commercial architecture, yet still today there remains a paucity of comprehensive studies proving the benefit of DSFs in different climate regions, and at different seasons. Although there are many published case studies *e.g.*(Hashemi, Fayaz, & Sarshar, 2010) (Pasquay, 2004) a lack of reliable experimental data and validated simulation studies is oft commented in the literature (Gertis, K., 1999) (H. Manz, Schaelin, & Simmler, 2004).

Ever more studies of DSF systems are required as their characteristics and operation are directly related to the climate in which the building is located, with solar radiation, wind and ambient air temperature all having an impact. This paper presents an experimental study focused on the temperature profile in a DSF in the maritime Irish climate during winter. This experimental study will form the basis for an extensive Computational Fluid Dynamics (CFD) study of different configurations of MSFs in the maritime climate. This study will in turn enable an evaluation of the appropriateness of MSFs in the context of the Irish climate and their ability for energy savings and comfort enhancement in Irish buildings.

DSFs are generally designed for different operation in summer and winter conditions. During Irish summer months DSFs generally operate in the 'open' mode. This implies that vents are opened at the bottom and top of the façade cavity. The air in the cavity removes excess heat by means of convective

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flow induced by the stack effect. This action prevents excessive heat accumulation in the cavity. If this occurs unwanted heat can transmit into the internal spaces. This can have a significant impact on the thermal comfort conditions within the building and create a greater necessity for the use of auxiliary cooling systems, hence resulting in an increase in energy consumption.

When the air is cleared from within the cavity, the temperature of the building envelope skin is lowered and heat transfer from the internal skin to the occupied space is reduced. Accordingly less heat is transferred from the outside to the inside, and less energy is required to cool the space.

In winter common DSF operation utilizes a sealed cavity, with no air circulation. For the winter scenario, the DSF cavity is warmer than the exterior temperature. As the air in the cavity is heated by the sun the temperature of the envelope skin increases and the temperature difference across the envelope skin reduces. Accordingly less heat is transferred from inside the building to the outside given a reduced temperature differential between interior conditioned space and the adjacent thermal zone. Significantly less energy is required to heat the space.

A greater proportion of research focuses on the evaluation and modeling of the summer operation of DSFs (H. Manz & Frank, 2005) with a paucity of investigation of the winter thermal buffer effect. Similarly the majority of studies investigate the airflow in DSFs with less emphasis on investigation of the temperature profiles in the cavity. In an 11 story building in Iranian winter conditions Hashemi et al (Hashemi et al., 2010) document a difference in temperature of 5–12 ◦C on the 7th floor and on 11th floor 7.5–10.5 ◦C more than the outside temperature. Vertical thermal stratification in the cavity is common in DSFs. The heated air in the cavity rises due to natural buoyancy, and a drop in air velocities at the top of the cavity leads to stratification. Thermal stratification is identified in monitored data (Hashemi et al., 2010) and simulation studies of mechanically ventilated facades (Pfuhler, Sikorski, & Kuhn, 2012). Hamza and Abohela (Hamza & Abohela, 2013) present an exploratory study of cavity stratification in non-uniform DSFs. Thermal stratification in the cavity has been shown to be influenced by a number of design and climatic parameters including solar radiation levels, shading device use and their colour, depth of the cavity of the double-skin, glazing types on both façade layers and design of inlets and outlets in relation to prevailing wind direction and speed amongst others.

This paper presents an experimental monitoring study of the temperature profile in the DSF of a commercial building in Dublin, Ireland that will form the basis of an extensive and validated modeling study of the appropriateness of DSF for this and similar climates. The impact of solar radiation levels, surface and cavity temperatures on DSF operation are presented.

EXPERIMENTAL METHODOLOGY

Experimental monitoring of a case study DSF is presented with focus on temperature characterization. Temperatures in the DSF were extensively monitored, with 9 temperature sensors installed on the three floors of the cavity. Interior temperature and external temperature are also monitored. Surface temperature readings were taken at intervals. Solar irradiance data was also attained for the location.

The DSF under consideration in this study is installed on the upper stories of an office building in Dublin, Ireland. It is a three-story façade (width x depth = 12m x 0.7m), is south facing and composed of external double-glazing and a single interior sheet of glass. The air cavity includes timber sun-shading louvers that drop approx. 750mm from the top of each level, are 250mm wide and horizontal. Automated venetian blinds shade the building envelope skin, and adjust their angle throughout the day. A metal grill divides each level of the DSF, which enable accessibility to each level and air movement between levels.

Although the DSF is analyzed in the ‘closed’ state there are 10mm gaps between the 100mm louvers, which allow ingress and exhaust of air. Such small openings have been shown to generate significant air flows (Gratia & De Herde, 2004).

a) b) c)

Figure 1 a) Double skin façade on upper stories of commercial building, b) corridor of double skin façade, and c) vents in closed state, with air gaps evident between louvers.

Dublin is located on the eastern coast of Ireland, on the northwestern periphery of Europe (latitude: 53°20′N and longitude: 6°15′W). It has a temperate maritime climate, of mild winter and summer seasons.

RESULTS

Winter temperatures were measured from January to April 2014. The following figures document the typical observed temperature profile for the DSF.

Cavity temperatures. The temperature in the 3 Levels of the cavity over a typical 4-day period in February is shown i**n** Figure 2**.**

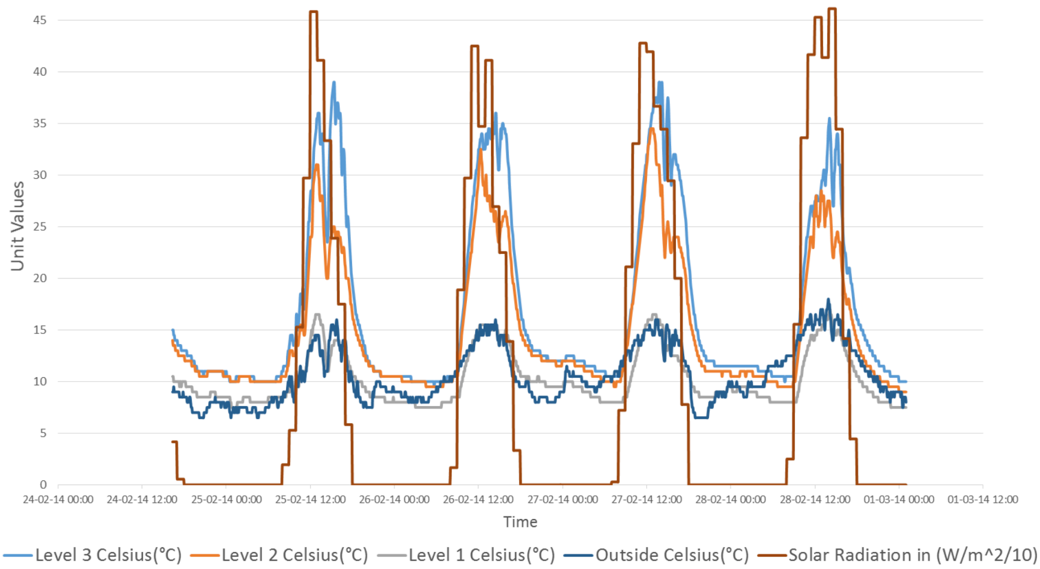

Figure 2. Temperature profile over 4 days of a typical sunny winter week, with outdoor temperatures in an 8-15°C circadian swing. Solar radiation is shown in brown and scaled to $(W/m^2)/10$.

The results show that T_{cav} during the day and night exceeds T_o on all levels except Level 1 of the cavity. The air temperature on Level 1 deviates little from the outdoor temperature but is often below even when exposed to high solar radiation. This phenomena is further shown in Figure 3 and 4. The outside temperature fluctuates in a 6°C range, whereas the temperature fluctuations in Level 2 and 3 are in the range 20-28°C on different days. This is in contrast to other studys in winter conduitions that show the fluctuation in T_{cav} to be less than that of the outside temperature (Hashemi et al., 2010). The temperature difference between the cavity temperature on Level 2 (T_{cav2}) and outside is 18°C at midday and 2-3°C at night. Similarly for Level 3, T_{cav2} - T_o is approx. 20°C at maximum and 2-3°C at nighttime. Maximum T_{cav3} reaches 35-39°C, when the outdoor temperature is 15°C. These high cavity temperature on the upper levels reduce the temperature difference across the building envelope, thereby impacting the heat loss across this boundary.

Temperature and solar incidence. Figure 3 and Figure 4 show the solar irradiance and the temperature on each level of the DSF for typical sunny and overcast days, charaterised by high and low solar radiation. T_o differs by 5°C between the days shown. However, T_{cav3} is almost 18°C higher on the sunnier and warmer day, showing the significant impact of solar radiation on a closed cavity in winter in sunny conditions.

Vertical thermal stratification is evident between the different façade levels with a large jump from the inlet level (T_{cav1}) to the middle of the façade (T_{cav2}) of up to 12-15°C.

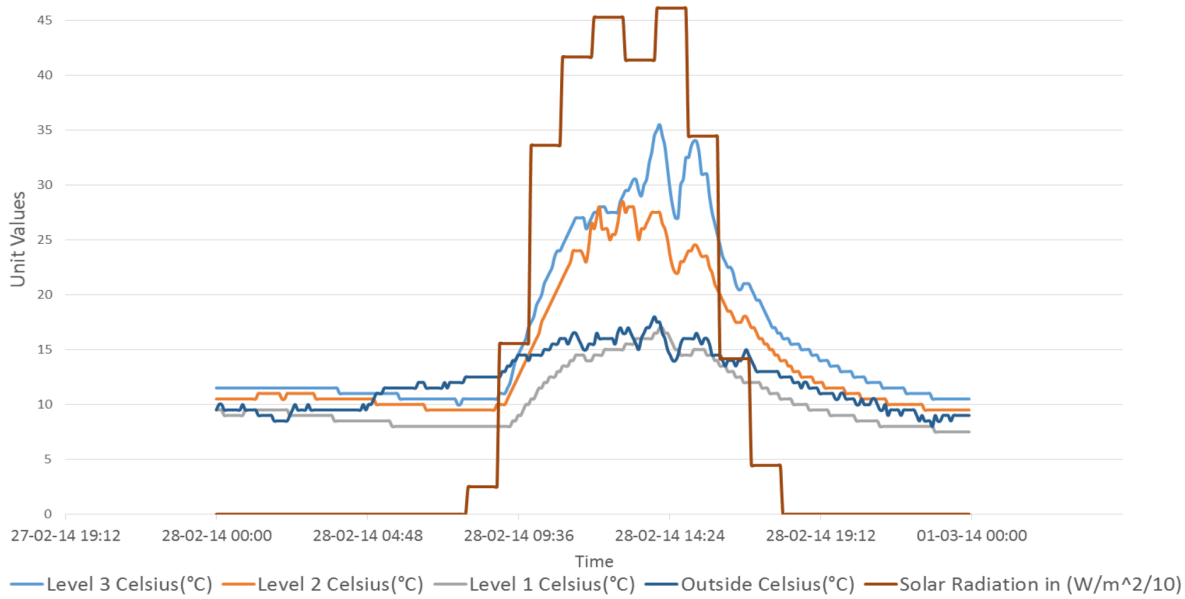

Figure 3. Temperature profiles for each level of the façade on a typical sunny day. Solar radiation (brown) is scaled to (W/m^2)/10.

In contrast on a typical overcast day the temperature in T_{cav1} is 2-4 greater than T_o. It is difficult to explain this given that all Levels of the cavity are exposed ot high solar radiation with no over-shadowing. The surface temperatures of the walkway grill and glass at Level 1 are signicant lower than temperatures at other levels and these possibly act to reduce the air temperatures in

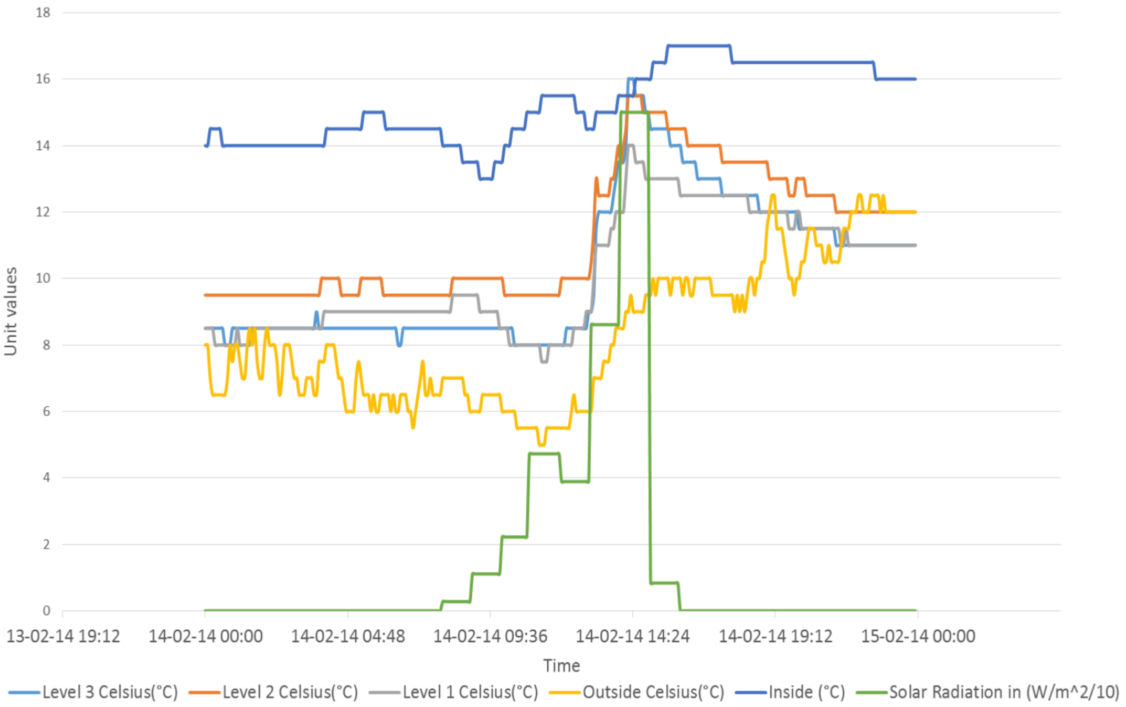

Figure 4. Temperature profiles for each level of the façade cavity on a typical overcast day. Solar radiation (green) is scaled to (W/m^2)/10.

Surface and cavity temperatures. Outdoor, indoor and cavity air, and boundary layer surface temperatures are **shown in** Figure 5**.** On this day the temperature in the interior space is controlled by the BMS from rising above 24°C. The surface temperature of the internal face of the building envelope boundary gains heat from the auxiliary internal space heating. Although Figure 5 shows temperatures for a discrete day of average solar radiation, the temperature profiles display a common trend on the different levels. The temperature gradient across the building envelope glazing surface drops in the upper floors; $T_{env\_ext\_3s}$ - $T_{env\_int\_3s}$ = 3.5°C and $T_{env\_ext\_3s}$ - $T_{env\_int\_3s}$ = 1.5°C. The gradient in surface temperature in Level 1 in contrast, increases $T_{env\_ext\_1s}$ - $T_{env\_int\_1s}$ = +5.8°C.

As expected, and similar to results reported by studies in hot arid climates Hamza et al (Hamza, Gomaa and Underwood, 2007), the surface temperature on the in-cavity surface of the exterior glazing of the DSF (T_{dsf}) is lower than the surface temperature of the in-cavity surface of the building envelope glazing (T_{env_ext}).

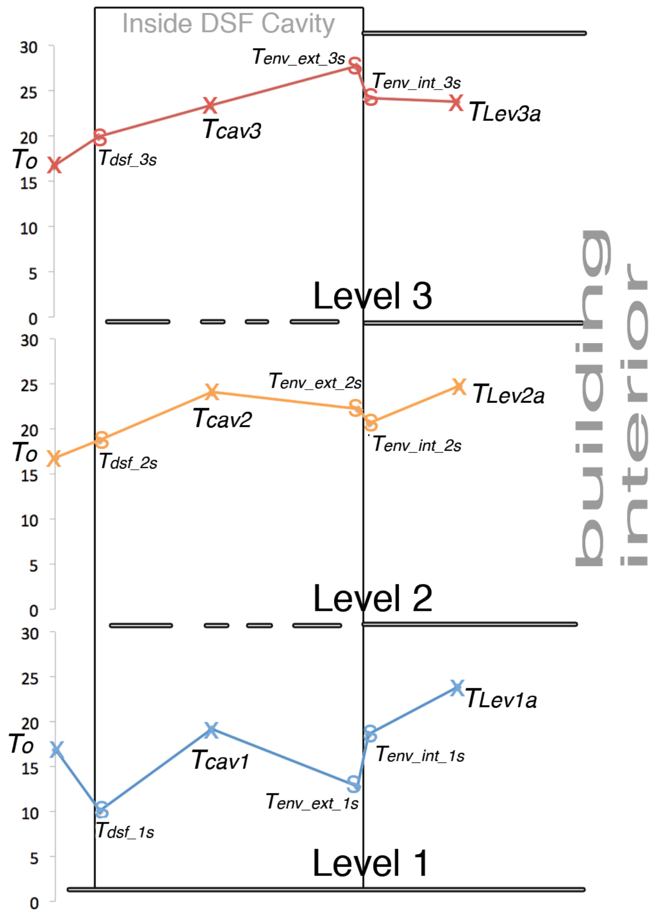

Figure 5. Temperatures outside, inside and on glass surfaces of DSF on a given day of average solar radiation (18/03/14). The points close to the DSF boundary and building envelope marked (s) represent surface temperature readings.

In Figure 5, Levels 2 and 3 cavity temperatures (T_{cav2}, T_{cav3}) are approximately equal to the indoor air temperatures (T_{Lev2a}, T_{Lev3a}). On Level 1 the cavity air temperature is significantly lower than on Level 2 and 3 (approx. 5°C lower) and on Level 1 the air temperature in the cavity is lower than that in the conditioned space in the building interior

SIMULATION STUDIES

Data presented in this paper is being used as the basis for a comprehensive simulation study of (i) zonal energy analysis using EnergyPlus and (ii) CFD modeling study using ANSYS. Further monitoring is planned during coming summer and winter seasons to enable validation of CFD and energy models. This will enable assessment of the specific conditions a DSF can benefit building performance and the optimum configuration and operation of the façade to enable passive heating and cooling and hence energy savings for the building. Airflow patterns in the closed and open states are investigated for turbulent and laminar patterns given different boundary conditions.

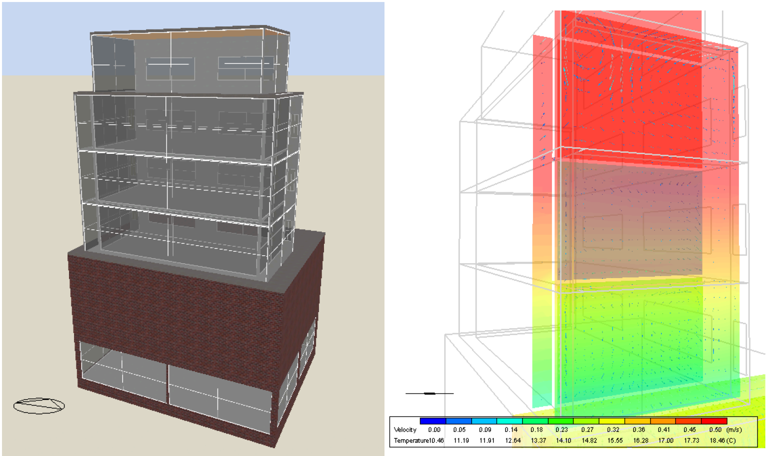

Figure 6. Energy model and CFD simulation of same model developed using EnergyPlus

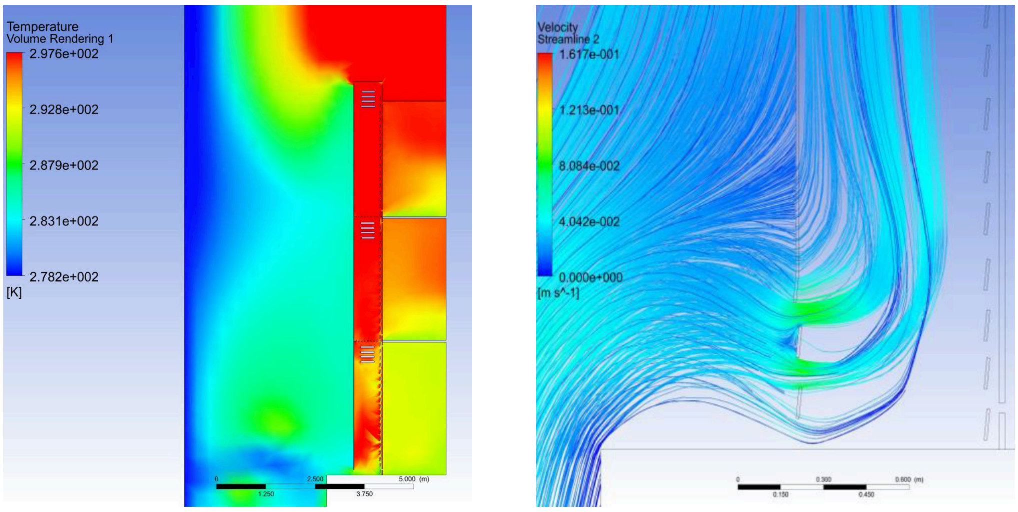

Figure 7. CFD model developed to assess temperature and laminar flow patterns in the DSF

CONCLUSION

Due to these higher air temperatures in the cavity relative to the outdoor temperature the external walls lose heat more slowly. This is beneficial to preheating of the inside spaces and heating energy conservation. However, in the DSF close to the building envelope the air temperature is often significantly higher than the heating set point implying a reversal of the standard winter temperature gradient seen across single skin building envelopes. Hence, the DSF can act to increase the internal air temperature even causing overheating, when the building is in free running mode. On days of high solar radiation levels it is proposed that the cavity be ventilated. Again this is not the case in Level 1, where the cavity temperature is regularly up to 10°C lower. Hence, the thermal buffer benefit of the DSF at the lower level is not discernible.

In contrast to many studies in the literature this study documents a consistently lower inlet temperature than outdoor air temperature. Saelens et al (Saelens, Roels, & Hens, 2004) demonstrated that the difference between the inlet temperature and the outdoor air temperature depends on the solar intensity and airflow rate. With solar radiation they showed the inlet temperature to be higher than the outdoor temperature, as did other authors (Heinrich Manz, 2004) (Fuliotto, 2010). Based on a review of these studies He et al (He, Shu, & Zhang, 2011) use a constant difference of +4°C difference in the summer case and +2°C difference in the winter case, between the inlet temperature and outdoor air temperature.

Based on standard heat loss assessment through the building envelope the DSF can be beneficial to

ACKNOWLEDGMENTS

The authors would like to thank Arup for enabling this research and for the case study building.

NOMENCLATURE

T_{cavX}	=	air temperature in cavity
T_{dsf_Xs}	=	surface temperature on external skin of dsf
$T_{env\_est\_Xs}$	=	surface temperature on external skin of building envelope
$T_{env\_int\_Xs}$	=	surface temperature on internal skin of building envelope

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Low-Energy Industrial Buildings for Climates of Emerging Countries

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ABSTRACT

The economic growth of developing and emerging countries pushes particularly the industrial sector, why a large demand for new industrial buildings arises. Though in many of these markets there is no traditional climate adapted architecture for industrial buildings as it mostly exists for dwellings. Thus many buildings for industrial applications are mainly built after European or American standards without respecting the local climate. Missing or misleading building regulations as well as missing general awareness and know-how in the local communities enhance this problem. The risk is to build a new generation of industrial buildings in these countries, having an unnecessary high energy demand for heating and cooling just by neglecting the climatic characteristics. Therefore this study proves the applicability of European concepts for low-energy industrial buildings for different climates for example from Russia and North Africa. Parameters such as air-tightness, window quality, solar orientation, thermal insulation and radiation reflectivity are analyzed and adjusted for optimizing the energy demand. The reduction of summer overheating is further under consideration because the post-installation of air conditioning systems should be avoided at any rate. For this purpose transient building simulations and air-flow-network simulations are used. As the basis for simulations of air-infiltration by appropriate product specific models, typical industrial building components are measured in an air-tightness test stand. The project focuses on light steel structure buildings which are often exported from Europe and the U.S. to emerging and developing markets. It is demonstrated how the energy demand of such buildings can be decreased already by small but efficient design changes.

INTRODUCTION

Emerging Countries mainly gain their economic growth by the industrial sector for which low labor cost and natural resources are usually the push factors. Thus a particular demand for new industrial buildings arises in these countries. However as large scale industry has often no tradition in these newly industrializing countries there is even little experience in buildings for industrial applications. For dwellings there is usually a long building tradition that was adapted for the local climate. But production buildings or plants are often imported from western regions such as Europe or the US. Due to the shipping constraints such imported buildings are usually built in light steel structure. Their design is typically executed in the producing country why the local climate and environment is often not well considered. Furthermore many of the companies settling down in threshold countries are global players who have already standardized their production buildings based on western climate requirements. Often only the insulation thickness is simply increased or decreased whether the building will be erected in a

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"warm" or "cold" climate. Other parameters such as window orientation or air-tightness are rarely recognized. Moreover the local authorities do not always have the expertise to assist and building regulations setting an energy standard as in Europe mostly do not exist or are at least less elaborated, as e.g. in Russia where the last recast of the building regulations dates from 2003 (SNiP 23-02-2003, 2003). That goes along with a still missing awareness for the need for reducing GHG-emissions. The risk is to build a new generation of industrial buildings having an unnecessary high energy demand. Hence in this project the energy demand for heating and cooling of light steel industrial buildings was analyzed for different climates. These analyses were determined by transient building simulations using the software package TRNSYS.

CLIMATE

As every climate needs an individual design, only general advises can be given in this project to make designers aware for how to reduce the energy demand dependent on the climate. For this purpose two hot North African climates (Casablanca, Morocco and Dar El Beïda, Algeria) and three cold Russian climates (Moscow, Samara and Irkutsk) were selected. Besides Ankara (Turkey) was chosen as this climate is hot in summer and cold in winter. A typical climate for exporting Central European countries is Würzburg, Germany. Exemplary the data for Irkutsk, Dar El Beïda and Ankara is shown in figure 1-3. Most important is the outside temperature, but also the solar radiation, the wind velocity and the temperature difference between day and night have a certain impact on the building performance.

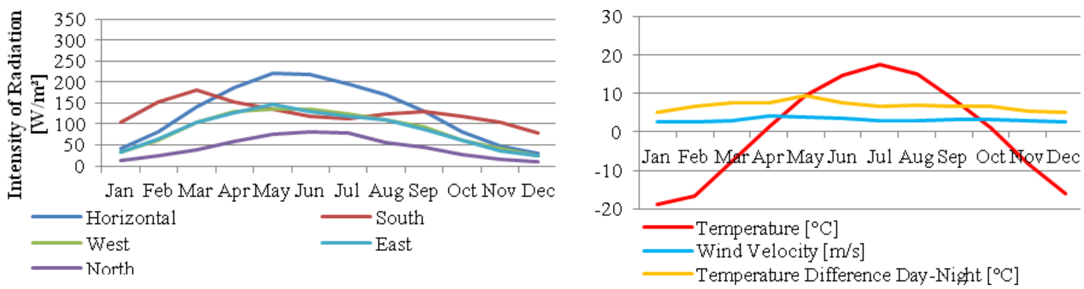

Figure 1 Radiation, temperature and wind velocity (Meteonorm) for Irkutsk (South Siberia)

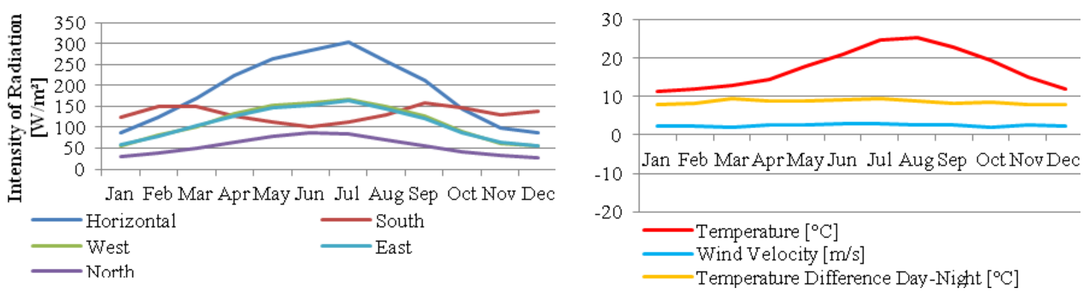

Figure 2 Radiation, temperature and wind velocity (Meteonorm) for Dar El Beïda (Algeria)

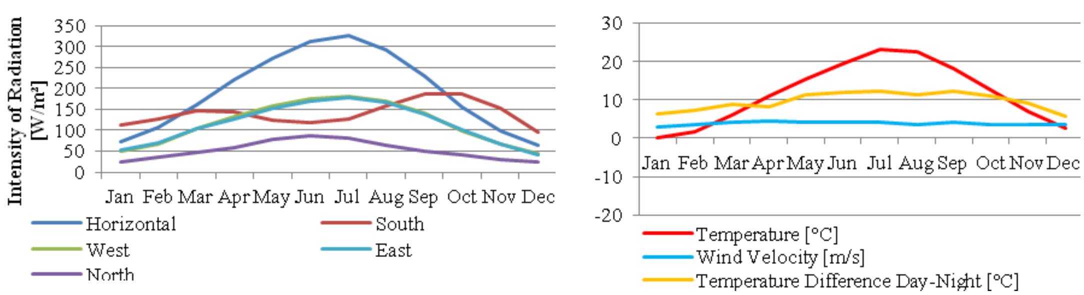

Figure 3 Radiation, temperature and wind velocity (Meteonorm) for Ankara (Turkey)

BUILDING PERFORMANCE

Industrial buildings in warm climates as Dar El Beïda or Casablanca usually never have any heating device. The temperatures during daytime are usually high enough also in winter and the temperature requirements in such buildings are in general quite low. Also cooling devices are still rare due to high investment and energy costs even if a cooling demand actually exists. But the economic growth will allow the installation of more and more air-conditioning systems in the future. To reduce the costs and the emitted GHGs, and of cause to improve the thermal comfort, the focus must therefore be set on overheating protection. Post-installation of cooling devices caused by misleading building design should be avoided at any rate. For the cold Russian climates cooling is not required, even if some hot summer days exist in the continental Siberia, but these temperature peaks are usually buffered by the thermal mass of the interior and the concrete slab. Most difficult is the design for climates like in Ankara, where the average temperature in July and August reaches 23 °C and in January it goes down to 0 °C. To find the right balance between a passive solar building and reduced summer overheating is the challenge.

Summer Overheating

The main summer overheating problems arise by wrong orientation of glazed surfaces. Movable shading devices are often not applicable and usually too expensive for industrial buildings. As summer overheating is a minor problem in Central Europe and as illumination is easy to ensure with horizontally oriented glazed surfaces, many exported industrial buildings have skylights. Figure 4 shows the simulated influence of the orientation and size of glazed surfaces in a typical light steel industrial building (1950 m^2 ground area, concrete slab). Internal loads by machines were considered with 40 W/m^2, as also used for production buildings in (DIN V 18599, 2011), based on (VDI 3802, 2003). In figure 4 the overtemperature degrees over 27 °C are shown. This method is used in Germany to limit overheating (DIN 4108-2, 2013). It sets a limit of 500 Kh per year which must not be exceeded if no air condition exists. Figure 4 shows that this limit is usually not reached in Central European climate why skylights are less critical. In warm climates like Ankara or Casablanca the horizontal orientation of glazed surfaces causes vast overheating if no air-condition exists and no controlled ventilation is used. If vertical glazed surfaces are used and oriented to the north the overheating is reduced significantly compared to skylights. The vertical south orientation also improves the overheating but for buildings without any heating demand the north should always be preferred. West and east oriented glazing is usually critical as well why for deeper buildings a combination of north and south oriented glazed surfaces in the facades is reasonable for North African Climate. For maritime climates like Casablanca the climate can already get tolerable by avoiding skylights. But for continental climates like Ankara other actions are required.

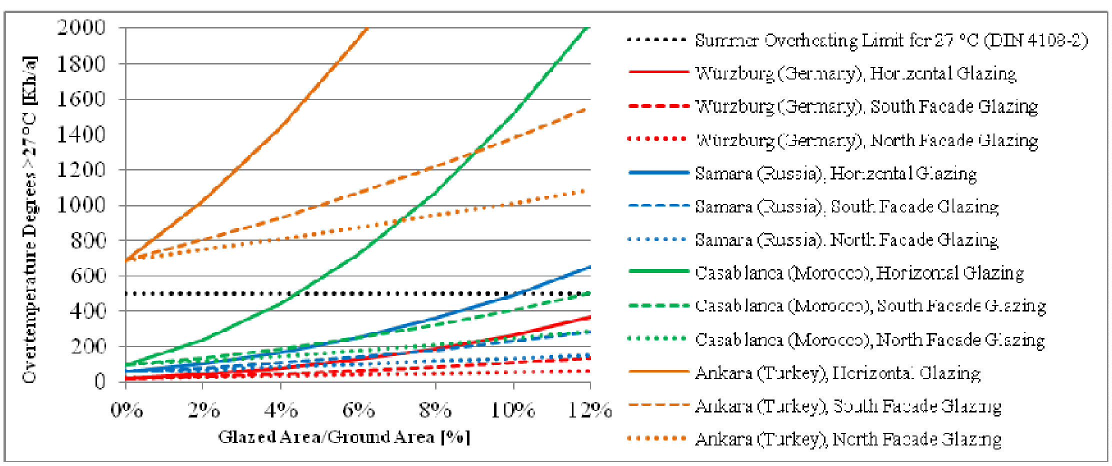

Figure 4 Overtemperature degrees (Kh/a > 27 °C) for different climates and glazing orientations

Figure 5 shows the impact of a controlled ventilation which is always turned on when the inside temperature exceeds the outside Temperature. Costs and energy demand of such ventilations are much lower than of air-conditions. Such mechanical ventilation should also be supported by natural ventilation to save energy, which can reach high ventilation rates like shown for the ventilation of industrial buildings in (Kistelegdi and Háber, 2012). Already existing openings like industrial doors and smoke vents can be used for it. How openings can be optimized for summer ventilation is e.g. analyzed in (Stephan, Bastide and Wurtz, 2011). Cross-ventilation though large openings like industrial doors including wind influences is discussed in (Seifert et al., 2006).

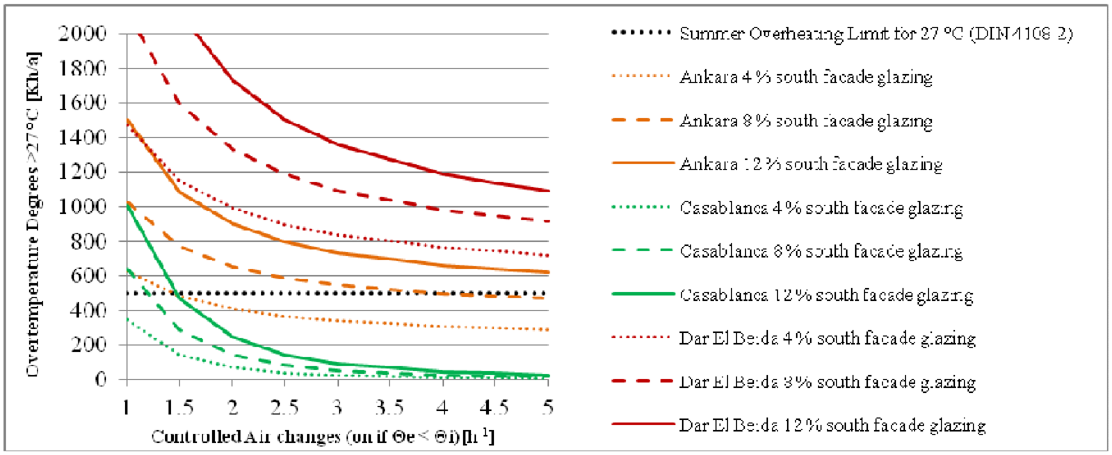

Figure 5 Influence of controlled ventilation on the summer overheating

The simulations in figure 5 show that even the German overheating requirements can be met for Ankara with glazed surfaces in the south façade, if there is a strong controlled ventilation. This is mostly due to the high temperature difference between day and night visible in figure 3. For Casablanca with its coast to the Atlantic Ocean the summer overheating is quite easily to reduce by controlled ventilation. At the Algerian coast to the Mediterranean Sea (Dar El Beïda) overheating is again much more difficult to avoid. Here the north orientation should always be chosen for window orientation.

In addition to the window orientation and the ventilation also the solar absorptance of the building envelope and the thermal capacitance of the interior are deciding for the thermal comfort in summer. Figure 6 (a) shows that an overheating reduction by low absorbing coatings is possible but the effect is not as important as e.g. night ventilation.

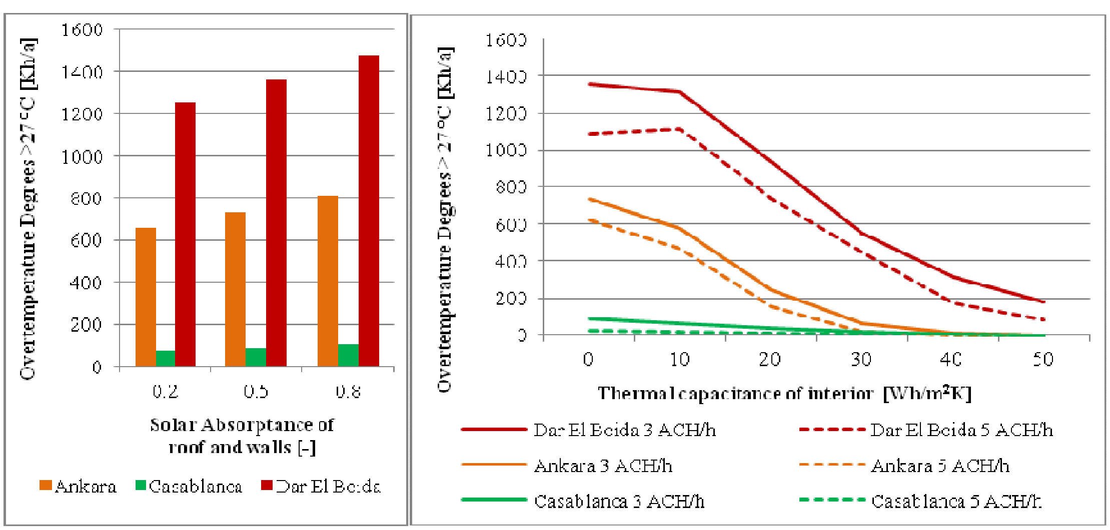

Figure 6 (a) Influence of the solar absorptance of the building envelope (roof, walls)
(b) Influence of the capacitance of interior on summer overheating (glazing south)

Figure 6 (b) shows the other important parameter, the thermal capacity of the interior. This of course interacts with the ventilation, as a higher capacitance can only reduce the inside temperature if the thermal mass is regularly cooled down by ventilation. The considerable effect is visible but anyway the simulation results can just be seen as an indicator for the importance of thermal mass. The real influence depends on many parameters such as the surface of the interior, the material and its heat-transmission resistance. These parameters will never be assessable in a design process but it is clear that an empty building overheats much easier than a filled storage.

The impact of air-tightness on summer overheating and the cooling demand is very low. In the simulations the differences between the cooling demand of an untight building (n_{50} = 5 h^{-1}) and a very tight building (n_{50} = 0.5 h^{-1}) was only about 2 %. Anyway big leakages should always be avoided.

Heating Demand

Air-tightness. Aside from the thermal insulation of a building the air-tightness is a major parameter for the energy performance. In many European countries like Germany, UK and France, tightness requirements already exist also for industrial buildings D: (EnEV, 2014), UK: (The Building Regulations 2010, 2013), F: (Méthode de calcul Th-BCE 2012, 2012). Even if these requirements are not always mandatory to meet, verifying the tightness allows lowering the infiltration losses in the energy performance calculation. In Russia unfortunately only tightness requirements for single building components of industrial buildings exist (SNiP 23-02-2003, 2003). To check if these single requirements are met is not possible on site and also fan pressurization tests after erecting the building are usually not carried out. This leads to a lower workmanship on site and probably increases the infiltration. In particular for cold Russian climate this is very critical. As air infiltration is caused by wind pressure and stack effects, beneath the wind velocity also the difference between the internal temperature and the ambient temperature is deciding for the amount of infiltration losses (Brinks, Kornadt, and Oly, 2014a), (Younes et al., 2011). Thus the infiltration in cold climates like Russia is even much higher than in temperate European zones. In warm climates like North Africa, where buildings are not heated and the climate inside and outside is similar during the year, infiltration is rather small (see figure 7). Adapted from measurements in an air-tightness test stand and air-flow network simulations, an infiltration model described in detail in (Brinks, Kornadt, & Oly, 2014b) was developed. This model was used to simulate the infiltration for typical light steel industrial buildings in the here mentioned climates. Detailed information about the air-flow network model is given in (University of Wisconsin Madison, 2009) and (Weber et al., 2003). In figure 7 the results for the infiltration of an 8 m high building (65 m x 30 m) with an n_{50}-value of 3 h^{-1} are shown. Due to the low temperatures in Irkutsk the infiltration is much higher during winter than for warm climates like Dar El Beïda.

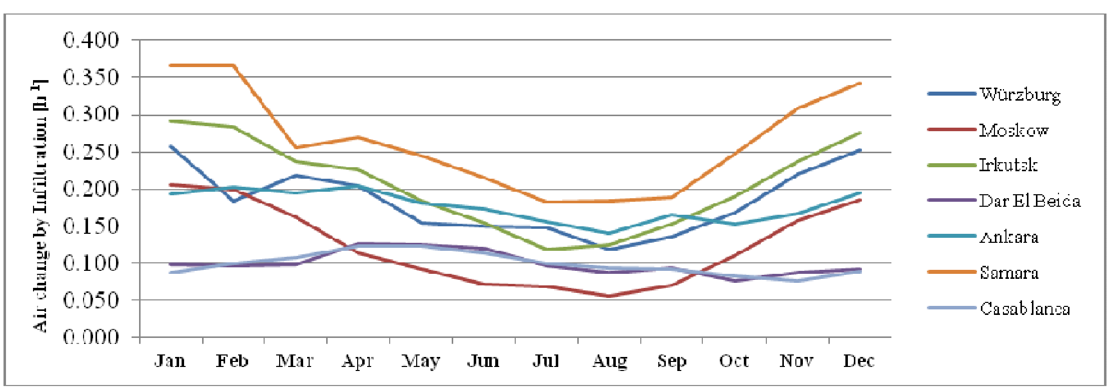

Figure 7 Air infiltration for an industrial building (n_{50} = 3 h^{-1}) in different climates

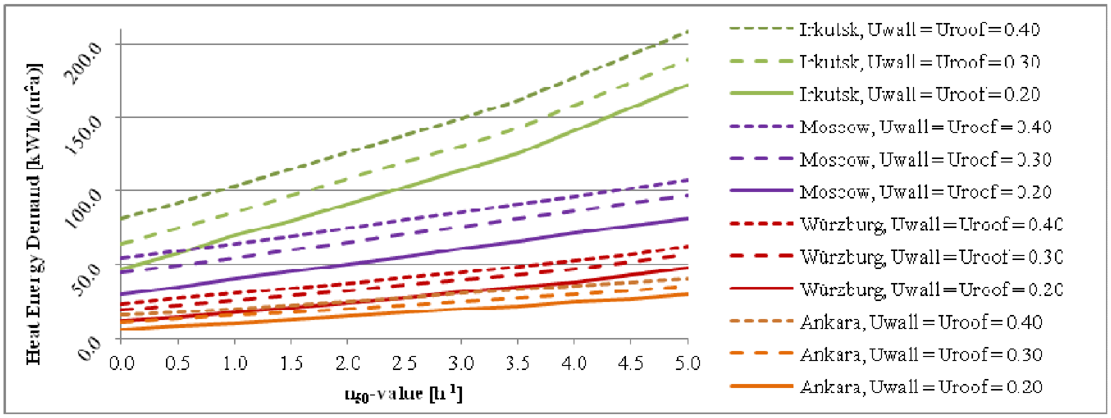

Figure 8 Heat energy demand dependent on the tightness and the wall and roof insulation quality

Figure 8 shows the impact of the tightness on the heat energy demand. Especially for Siberia it is even more important to tighten the building than to increase the insulation thickness of the roof and walls. Reducing the n_{50}-value from 3.0 h^{-1} to 1.5 h^{-1} saves as much energy as reducing the U-value of the roof and all walls from 0.4 W/m^2K to 0.2 W/m^2K. In general promising methods for air-tightness design in light steel buildings were already developed e.g. described in (Brinks, Kornadt, and Oly, 2013). But tightness is not only a question of design but of workmanship, thus it cannot be assured, that European standards are realized in Russia as well. Anyway tightness requirements for Russian industrial buildings are currently not existing even if requirements for Russian dwellings are in the range of European standards (SNiP 23-02-2003).

Another important aspect is that infiltration losses via open doors are not recognized at all in any known building regulations or codes. For dwellings such losses may mostly be negligible but losses via large industrial doors can have a large impact on the energy balance. This lack was already discussed in (Brinks, Kornadt, & Oly, 2014c) where rough simulations based on (Dascalaki, E. et al.. 1995) were carried out. These calculations already show a significant impact for Central Europe but it seems to be even higher for Russia due to larger buoyancy effects.

Solar Gains and Orientation of Glazed Surfaces. The orientation of glazed surfaces is not only important for summer overheating, but passive solar gains can reduce the energy demand of buildings considerably. For residential and office buildings this is already shown by many studies as (Cappaletti et al., 2014) or (Boubekri and Boyer, 1993) and also first analysis for industrial buildings in Central European climates exist (Brinks, Kornadt, & Oly, 2014d). Figure 9 shows how the heating demand changes for different oriented glazed surfaces (40 mm polycarbonate, U = 1.10 W/m^2, g = 0.56) in Russian climates. Here a low-energy production building with 17 °C inside temperature, 40 W/m^2 internal gains, an n_{50}-value of 0.5 h^{-1} and a U-value of walls and roofs of 0.20 W/m^2K was simulated. Due to the high solar radiation in Irkutsk during winter (approximately twice as high as in Central Europe), here the orientation has the most significant impact.

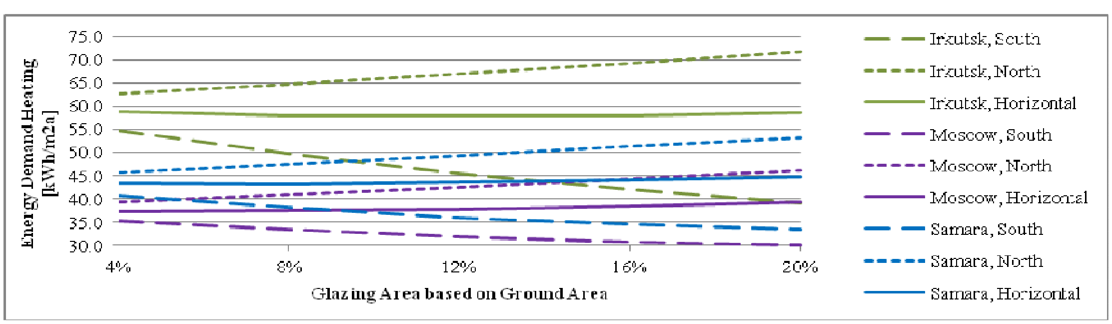

Figure 9 Energy demand for heating dependent on the glazed surfaces for Russian climates

Installing large glazed surfaces on the south façade instead of skylights can reduce the energy demand by up to 30 % if the façade is not shaded. For Moscow the effect is smaller as the solar radiation is lower. Anyway in Russian climates it is advised to use as much glazed surfaces in south façades as possible if facades are not shaded. The glazing quality, particularly a high g-value, is of course to be respected. In climates like Ankara with hot summers and cold winters the situation is more complex. Thus the impact of the glazing orientation and surface on the energy demand for both, heating and cooling, was simulated. The results in figure 10 show that increasing the glazed surface in general decreases the heating demand and increases the cooling demand. But the leverage effect of this parameter is different for all orientations. For the south façade the total energy demand (heating + cooling) decreases with a larger glazed surface. For the north façade it increases slightly and for the horizontal (skylights) it increases considerably. This means that increasing the horizontal glazing area should usually be avoided. Anyway general advises to increase the glazed south façade area in such climates cannot be given. This decision depends on if a cooling device is installed at all and which (primary) energy is used for heating and cooling. Thus a decision has to be taken individually for any project.

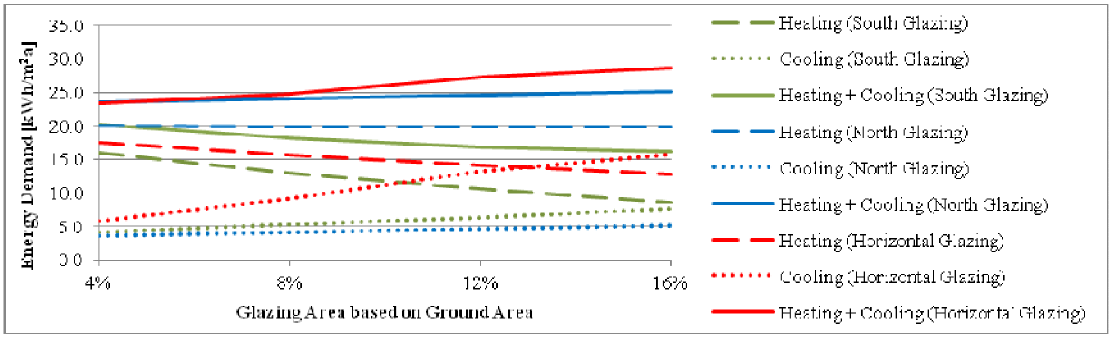

Figure 10 Energy demand for heating and cooling dependent on the glazed surfaces for Ankara

CONCLUSION

The building simulations carried out show the consequences of exporting industrial buildings designed for Europe without adapting the building envelope design to the local climate.

In hot climates it is mandatory to avoid skylights and replace them by glazed surfaces in the façade. If summer overheating is not critical and a heating demand exists in winter, the glazed surfaces should be oriented mainly to the south, otherwise to the north. To keep the cooling demand low or even avoid it, controlled night cooling is an energy-saving solution. Especially at night high ventilation rates are required that should be ensured by mechanical ventilation supported by natural ventilation. Reflective coatings of the roofs can be a small added value as well. Buildings with little thermal capacity are usually more susceptible for overheating why overheating protection becomes more complex.

In cold climates like in Russia the saving potential by orienting vertical glazed surfaces to the south is very high. Due to very high solar radiation in winter especially in Siberia these glazed surfaces should be increased as much as possible as overheating usually is no problem in such regions. Furthermore the air-tightness of industrial buildings in Russia is very important but is unfortunately not considered sufficiently by current building regulations. Improving the tightness is even more effective here than increasing the insulation thicknesses. Moreover this solution is also low cost, but appropriate quality controls like fan pressurization tests should become mandatory also for production buildings and warehouses. Here the most important need for action exists.

Most difficult is the design for regions with hot summers and cold winters like Turkey. Here building simulation should be used, as general advises are difficult to give and the design also depends a lot on the kind of energy used. A potential for heating in these countries is surely the use of solar energy. Here further research for seasonal thermal solar storages is required. Due to the long heating period and the high solar radiation in South Siberia this could also be interesting as a heating support for Russia.

ACKNOWLEDGMENTS

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Flexible and Environment Responsive Mass Housing in Bangalore, India

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ABSTRACT

Bangalore is one of the fastest urbanizing cities in India due to rapid increase in population and migration of people from varied and distinct cultural backgrounds. This has resulted in rapid development of high density housing characterized by towers of repetitive units. Most modern housing developments are focused on the repetition of units suitable for an average dweller, without taking into consideration the diverse and dynamic needs and wants of individuals and society.

What is ironic is that for centuries now, most societies have produced housing it requires, naturally and indigenously. The traditional vernacular architecture has always been in empathy with the environment.

This project develops options for a prototype housing unit and tests it by an analysis using the TAS software package for achieving flexibility without compromising on natural ventilation. It then develops a residential cluster which can be used as a model for future developments in Bangalore.

INTRODUCTION

India is urbanizing at an unprecedented rate due to an immense increase in population and migration of people from distinct cultural backgrounds and traditions from the suburbs and villages into cities. This has resulted in rapid high density housing development in the city resulting in towers of repetitive units. Migration has given rise to more mixed-cultural societies. These residents from varied cultural backgrounds and traditions, therefore, require residential areas or spatial configurations of apartments to be adaptable, comfortable and culture friendly for a better living. This cultural heterogeneity demands a different approach to housing. Also, the current housing industry is very limited when it comes to catering for long term social needs. It is crucial to take into consideration the different needs and patterns of individuals or each family.

While traditionally most buildings fundamentally responded to the climate, in the recent times, the dependence on mechanical heating and cooling devices has increased immensely, bringing about a change in the housing form and also the lifestyle of the people. Energy consumption in the building sector alone is more than one-third of the national energy use in India (Plea, 2013).

In architect Charles Correa's words:

"In a third world country like India, we simply cannot afford to squander the kind of resources required to air-condition a glass-tower under a tropical sun." (Correa, 2012, p.21)

India being home to diverse climatic conditions and energy availability being scarce it is important that buildings use passive means rather than mechanical air conditioning and heating. The term 'passive' refers to those design techniques which, in order to enhance thermal comfort, utilize the favourable and

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minimize the unfavourable elements of the local climate.

This project aims at developing a prototype for urban high-density mass housing to accommodate passive design features while providing flexibility in design to cater to the varying cultural backgrounds of the migrant population in Bangalore and assessing it using TAS software package.

The objective is to develop a flexible unit to suit the demographics and the changing family needs. The current housing industry is very limited when it comes to catering for long term social needs. It is crucial to take into consideration the different needs and patterns of individuals or each family. Currently most mass housing in the city are being taken up by commercial real estate developers resulting in high rise structures with repetitive units.

CONTEXT

Bangalore, situated in the south of India, is the third most populous city in the country with a population of 8.4 million. It is located at 12.97°N 77.56°E with an average elevation of 920m on the Deccan Plateau.

The climate of the district is classed as the seasonally dry tropical savanna climate. Bangalore experiences a pleasant climatic condition, with occasional heat waves during the summer. In summer the temperature goes up to 38°C during the day and falls to 20°C at night. In winter the maximum temperature goes up to 27°C during the day and goes below 17°C during the night (Pib, 2008). The primary wind direction in Bangalore is south-west. During the months between January and March and October and December the wind direction is from north-east to south –west and between April and September it is from south-west to north-east.

The design criteria in this zone are to reduce heat gain by providing shading, and to promote heat loss by ventilation. Bangalore being located on a relatively higher altitude experiences a pleasant climate and does not require mechanical cooling for most part of the year. Effective ventilation and air circulation can cut down the energy needs in the city.

The city, earlier, known as the “Pensioner’s paradise” is now India’s Silicon Valley with the unprecedented rapid growth caused by the boom of the Information Technology sector. Also, various MNCs have set up their R&D centres in Bangalore, attracting young professionals in search of career or entrepreneurship (Forbes India, 2014).

As a result of the migration from other cities and town, the demand for housing has really gone up in the city, mostly in the rental market. Bangalore witnessed the launch of 35,000 residential units in the year 2012 and nearly 8,100 in the first quarter of the year 2013 (The Hindu, 2013). However, the current housing developments follow a trend of “cloning”, where the developments are focused on the repetition of units suitable for an average dweller, without taking into consideration the diverse and dynamic needs and wants of individuals and society.

The potential occupants of the residences mostly being young professionals migrating from other cities, an ideal solution would be to incorporate flexibility in the planning to suit the different lifestyles and also provide for incremental growth in the housing. Also, the demand for rental properties being high, flexibility in the planning would help cater to a diverse crowd. For instance, the potential residents may vary from a group of individuals sharing a unit to a newly married couple or a growing family.

Living Arrangement in India

The living arrangement in India traditionally has been a multigenerational household where it is the duty of the child, especially the male, to provide parental support in their old age. Nowadays the shift in the demographics such as migration for employment has resulted in children leaving the residences shared with their parents and has resulted in many nuclear families in the city.

For instance, 73.6% of the household in this state are working couples and these young working populations mostly take up studio apartments as a temporary base and move out to a bigger place after a few years when the family expands or when the elderly parents move in with them.

Figure 1 Living Arrangement in India (Source: Authors)

In Bangalore, in the past few decades, it has mostly been plotted developments where people buy the land and develop their house according to their requirements.

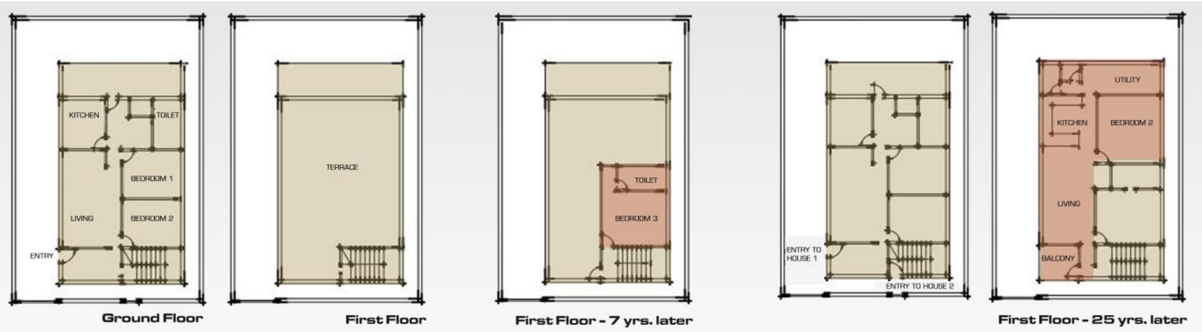

Figure 2 Example of a plotted development (Source: Authors)

Site

The site measures 1.6 acres and is located in South Bangalore, situated off Bannerghatta Main road, on Ranka Colony Road. Ranka Colony Road is developing to be one of the busiest roads, connecting Bannerghatta road to rest of South Bangalore.

Figure 3 Site Location and surroundings (Source: Authors)

DESIGN

Concept

The design attempts to bring together flexibility and passive design strategies in a prototype housing unit providing for expansion and division within a mass housing to suit the Indian living patterns. The design comprises of group housing with set defined boundaries for each housing unit.

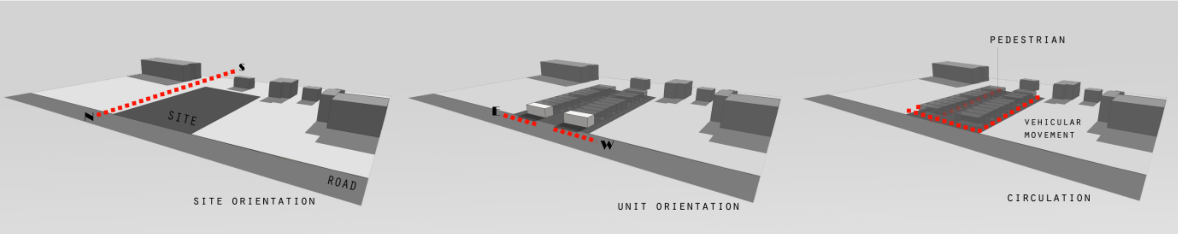

Figure 4 Orientation (Source: Authors)

The basic form was developed based on certain passive design strategies suitable for the tropical savanna climate of Bangalore.

- Orienting the longer façade in the North-South direction as east and west façade receive higher intensity of solar radiation throughout the year.
- Shading the east and west façade by staggering the units.
- Facilitating stack effect, which is very effective in the Bangalore climate.
- Taking advantage of the predominant wind originating from the east and west direction by having more openings in that direction, maximizing cross ventilation
- Possibility for controlled adjustable shading on the east and west façade.

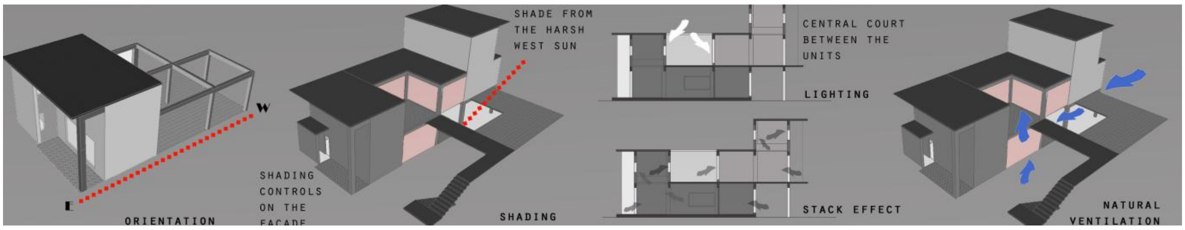

Figure 5 Passive Design Strategies (Source: Authors)

The concept of flexibility has been worked upon based on the ideology of providing a framework and giving indication to the possibilities of spatial arrangements. Initially, all units have the same basic essential form along with a steel frame structure for future expansion. The frame structure sets the boundary of the unit and gives the occupants the freedom to expand at their convenience and also to decide the materials for the infill. When it is just a basic unit, the open spaces enclosed by the frame, serve as a garden space or a backyard for the house. The framed structure forms a grid plan allowing the occupants to construct anywhere along the grid forming arrangements to suit their requirements. The planning has been done in such a way that each unit has its own court and once the unit is fully expanded, it encloses the court.

Also, two units have been interlocked together to develop a pattern of massing to achieve high density housing. At the same time, the upper unit shades the lower one from the harsh west sun. Also, the arrangement provides for unblocked cross ventilation as shown in figure 5.

In the case of a contraction in the family size, there is the possibility of dividing a single unit into two small units which can be used as an office space or a studio apartment.

The frame structure defines the boundary for each unit providing three grids for future expansion with the fourth grid serving as an open court all throughout.

Also, the units have fixed entries, even upon division.

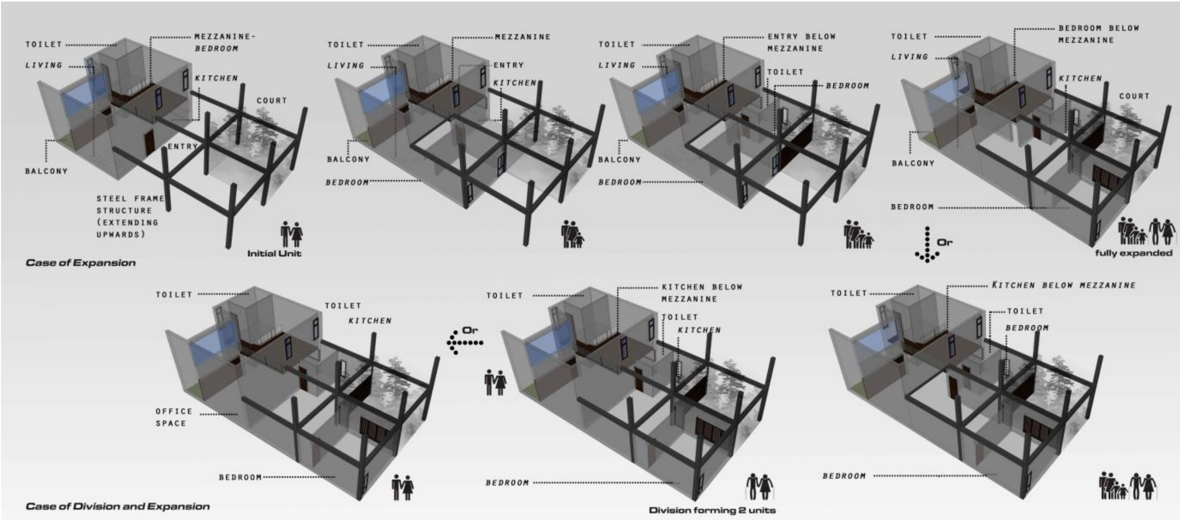

Figure 6 Cases of Expansion and Division (Source: Authors)

The above image shows the possibilities of arrangement as the unit expands. The first is the basic unit with a kitchenette space and a toilet and a mezzanine space which can be used as a bedroom. This would suit a single occupant or a couple.

As the family expands and requires more space, the unit can be expanded by constructing along the grid as seen in the second, third and fourth case where the unit can be transformed from a studio apartment to a three bedroom housing unit.

However, if the family contracts, for instance, the children move out and the elderly parents are the only occupants of the unit and they do not require so much of space, the unit can then be divided into two. This can be done by constructing a wall between the basic unit and the expanded wing forming two units with separate entries.

Massing

The massing in this context has been worked out along a central pedestrian pathway with the interlocking housing units on either side, while the vehicular movement has been restricted to the periphery. Also, the units on either sides of the central path have been staggered to maintain privacy in all the units.

The central pedestrian route opens up to several shared courts which lead on to the private courts of the housing units.

The prototype units can be arranged to form different types of massing ranging from row housing to low-rise apartments and high rise apartments where there is a space constraint.

PASSIVE DESIGN STRATEGIES AND ANALYSIS

TAS software

The software is split into three main programs, the 3d Modeller, Building Simulator and Results Viewer. As the first step, the 3d modeller is used to create the building model for simulation. Here, the different spaces are assigned different zones.

Next, the model created is exported to the building simulator. In this program, the building components are assigned its materials. Using this program, one can choose which apertures are open, when and by how much. The internal conditions are assigned for the different zones depending on the number of people occupying the space and considering factors such as lighting, etc.

Once all the information has been entered, the model is exported to the result viewer. Here, any number of parameters such as relative humidity, dry bulb temperature, etc. from any number of zones or surfaces can be displayed and compared in a tabular and graphical format.

Parameters considered:

Materials

External and Internal wall – Brick wall
Floor Slab – Concrete
Window frame – wood 50mm width

Aperture type and schedule

The stack windows in the double height space were considered to be open all through the day. The windows in the main living room were kept open during the day from 7:00 to 10:00 and in the evening from 17:00 to 19:00. The bedroom windows were considered to be open during the night from 18:00 to 07:00.

Finally, in the Result Viewer the dry bulb temperature for all the zones were compared to study if it was within the comfort range. This was repeated for the different stages of flexibility.

Comfort Range

For all climate and building types, the National Building Code of India specifies the use of two narrow ranges of temperature: summer (23–26 °C) and winter (21–23 °C), (BEE, 2005). These standards are based on ASHRAE standards, which are not validated through empirical studies on local subjects. However, India experiences diverse climates, thus it is not proper to define a single comfortable temperature for the entire country, as it would vary region wise.

Based upon a comfort survey conducted all over the world, a relation has been derived between comfort temperature (Tc) and outdoor temperature (T0) [3] as

$Tc = 12.1+0.53T0$.

Another relation was obtained for Pakistan which has almost similar climatic conditions as in India as

$Tc = 17.0+0.38T0$.

Where,

Tc is comfort temperature and T0, mean monthly maximum and minimum external temperature. (Chandel and Aggarwal, 2012)

Based on this relation, the comfort range for Bangalore for the month of May was calculated to be 26°C - 29°C and 24°C - 28°C for December.

The analysis has been carried out based on both the comfort ranges, the one based on the ASHRAE standards and the one derived from the equation.

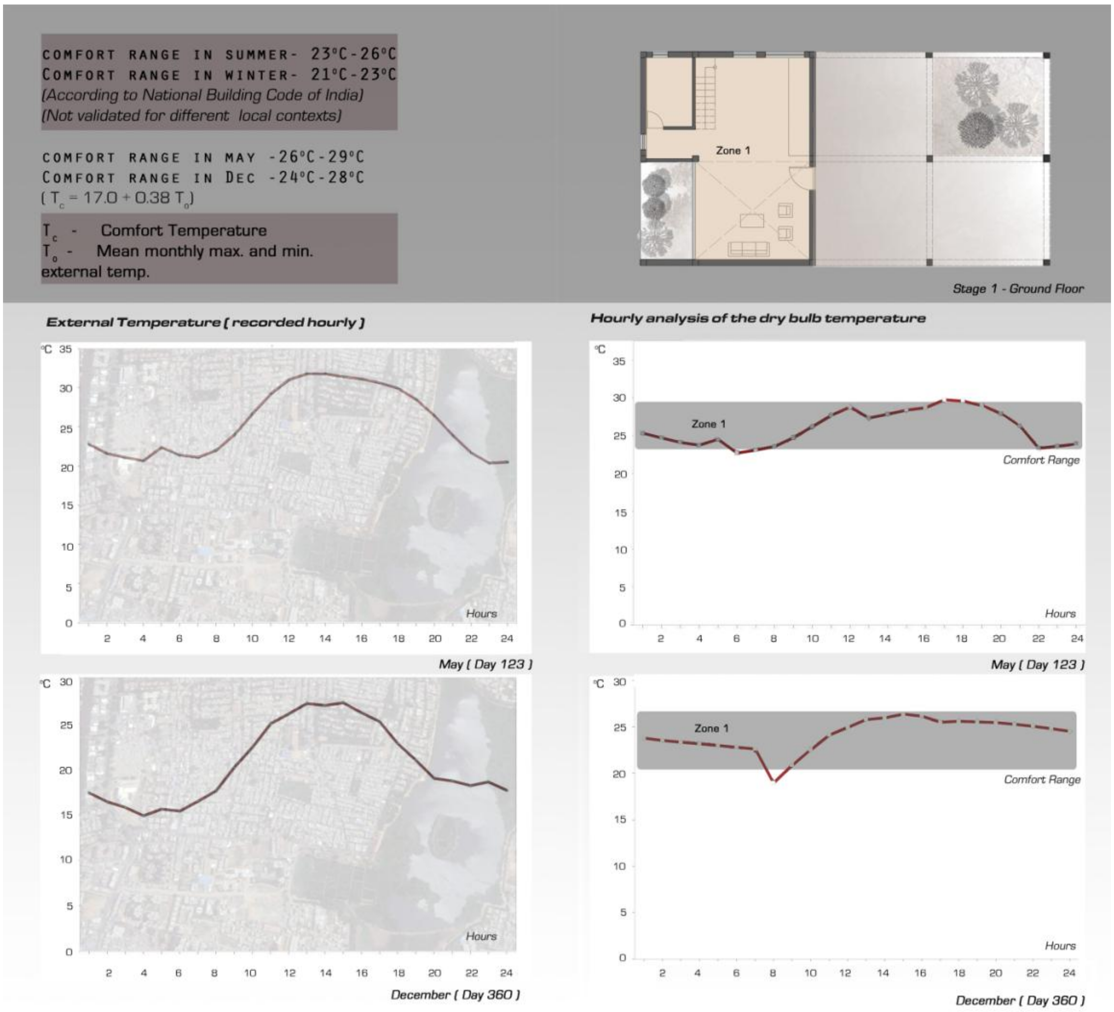

Figure 7 Variation in dry bulb temperature in a basic unit (Source: Authors)

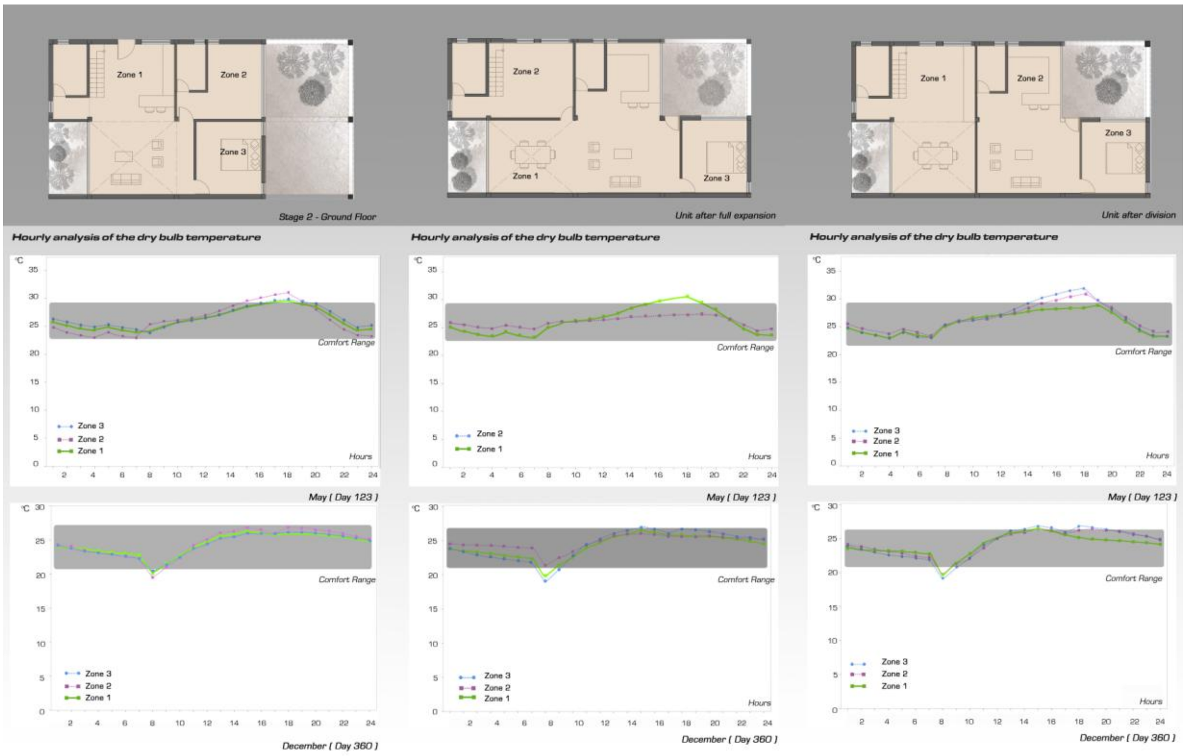

Figure 8 Variation in dry bulb temperature after expansion and division

Design iterations

First, the basic unit was simulated and it was observed that the double height space helped reduce the dry temperature within. However, it was more effective when the outlets where at the highest point and the inlets were narrow. From a comparison of the dry bulb temperature of the internal zones, it was observed that the temperature in the mezzanine was always maintained at a higher level making it an ideal zone for winter time.

Also, it was observed that the temperature within reduced with the addition of a covered balcony on the west façade. And as the housing unit expanded, the temperatures in the rooms were maintained within the comfort range when the central portion of the unit was left open with no partitions.

CONCLUSION

In a country like India, the cultural heterogeneity and the changing living patterns demands a flexible approach to housing. Also, energy consumption in the building sector alone is more than one-third of the national energy use in India. India being home to diverse climatic conditions and energy availability being scarce it is important that buildings use passive means rather than mechanical air conditioning and heating.

In terms of the factors contributing to the success of a flexible housing, most often a combination of both use and technology prove to be more effective as seen from the case studies. When the method of flexibility is just confined to the interior of an existing shell, the amount of choice and control of the occupants get limited. From the scale of a single housing unit to mass housing, with careful consideration of use and technology without much additional costs and over complicated technological systems, flexibility can be achieved successfully.

Coming down to the project, in a climate like Bangalore's with careful planning and by adopting climate responsive strategies, the energy use in the residential sector can be cut down drastically. It is evident from the TAS energy modelling analysis that the indoor temperature can be maintained to suit the comfort of the occupants without depending on mechanical cooling systems.

In terms of flexibility, the frame structure defines a boundary for each of the unit allowing it to expand or contract without affecting the neighbouring units much. Also the prototype design of the unit can be adopted to develop a variety of housing types such as row housing, high rise or even just a group of four houses.

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Abodes in Adobe

Savneet Kaur, B.Arch, M.Sd
Imarat Architects

A BRIEF REVIEW

Designing Climate Responsive residences in the composite zone of Northern India as a means to conserve natural resources

The climate of the plains of northern India is characterized by harsh summers and extremely cold winters which results in buildings being air conditioned all year round, a colossal waste of energy, adds to the carbon footprint. This paper is based on the research and construction of a prototype of a small residence constructed with the object of developing a building vocabulary of materials and techniques which cater to the contemporary tastes yet derives its roots from the vernacular architecture of the place.

As 90% of the construction in rapidly urbanizing smaller towns of India is 'individual homes' it is important to develop/construct a model or sample of a 'shelter' that is affordable, comfortable, aesthetical, functional and eco-friendly.

The architect spent over four years in developing this prototype and the paper will elucidate the solar passive design techniques and the material selection and construction methodology that has gone into the construction of this 'home' which has dispensed with the need for air-conditioning and also used eco-friendly materials in a place like the NCR. The results monitored in this cottage showed 28 degree Centigrade ambient inside temperature in the month of June when the outside temperature was 40 degrees.

A truly revolutionary concept, that needs to be popularized.

INTRODUCTION

Construction Industry is the largest growing sector in the Indian economy and is also responsible for a heavy depletion of our natural resources, from timber in building, to coal in burning bricks in kilns, to oil in transportation and mostly in the production of cement and steel. Our buildings need to be designed in response to the climate and with regard to the environment. If 90% of the buildings are for residential purposes, does that imply *"Our homes are destroying our environment?"*

Design leads to manifestation of human intention. What we make with our hands must honor the earth, and they must not only rise from the ground but return to it, without causing any harm to any living system. This is ecology, this is good design.

Are we aware that more than 80% of our construction activities cater to less than 5% of our population? That an average house for a single family uses 8 times the cement needed for its stability?

INTENT AND OBJECTIVES OF APPLIED RESEARCH

Our firm, Imarat, has been committed to building green for a number of years now, using **solar passive design** and **eco-friendly material**. It has been our prime objective to **bring good architecture to the door step of the common man**– which needs designing costeffective homes, that are aesthetical & provide all modern day conveniences. As the vernacular architecture of the Indo- Ganges plains offers very valuable lessons in terms of planning & material, it was imperative to combine traditional wisdom with contemporary necessities.

Objectives:

1. To develop a building vocabulary of materials and techniques which caters to contemporary tastes, yet derives its roots from the **vernacular architecture** of the place.
2. To incorporate the wisdom of vaastu-shastra (the ancient Indian text on building design and construction) with the principles of climatology.
3. To build our basic structure, an average home that blends with nature, while maintaining its unique sculptural beauty and aesthetics.
4. To use and promote construction material and technology which is environment friendly and locally available.
5. To develop a module/sample of a shelter that is affordable, comfortable, aesthetical functional and ecofriendly.

PROCESS/APPROACH

Site Analysis

The site is in a mango orchard in agricultural fields on the outskirts of Karnal.

1. Topography (Site Profile): The plot is in a mango orchard in agriculture land, the design is site responsive with fields on one side.
2. Climatic condition: The climate of Karnal is monsoon-influenced humid subtropical climate with high variation between summer and winter temperatures and precipitation. It has relatively dry winters and has a prolonged spell of very hot weather.
3. Maximum temperature of the city reaches up to 48°C in summers and minimum temperature in winter season falls down to 1°C. January is the coldest month with average minimum temperature of 7°C.
4. Rainfall: The annual rainfall of the Karnal is recorded to be about 600mm. Rainfall is unevenly distributed and decreases from south east to southwest. Rainy season starts by July and ends in September. About 80% of the total rainfall is received during this period. Some amount of rainfall is received from western disturbances during the winter season.
5. Wind Flow: It is influenced by southwest monsoon winds in the summer and westerly and northwesterly winds during the winter. The wind direction is NW and SE.
6. Population: Karnal metropolitan area has a population of 3, 03,425 persons. The district has a population density of 598 inhabitants per square kilometer.

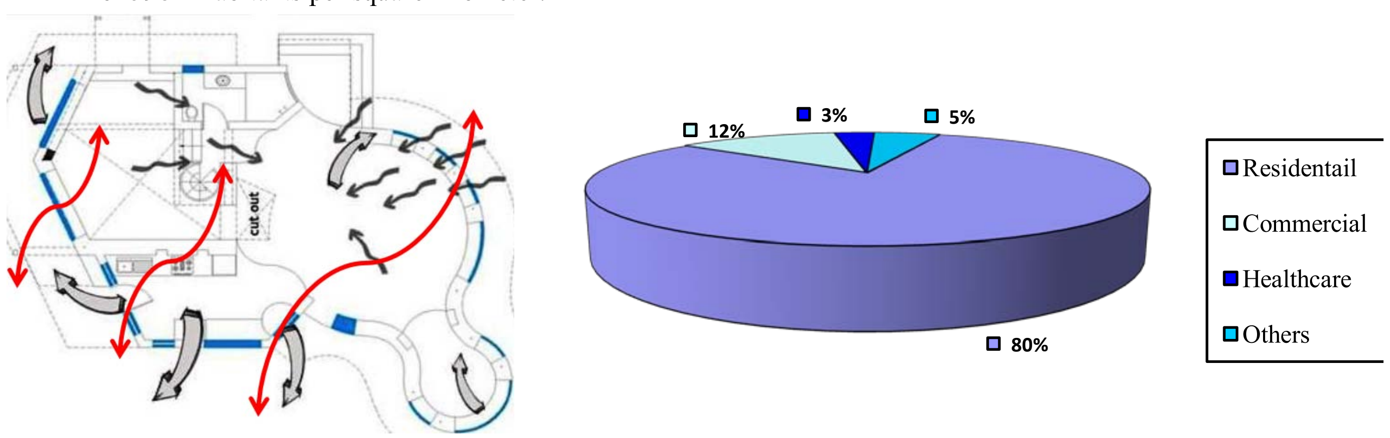

Figure 1→ (a) Wind Flowinside the building (b) Population Distribution

Design Development

The overall form of the building was detailed by the trees on site. No tree was felled – rather, the building was designed to fit in the open space between trees. The flowing curves of the building meander between the trees and the building height was kept lower than average height of a tree i.e. 17’.The built structure looks a part of its surrounding, merging in the natural grove. The basic plan is designed with the principles ofsolar passive planning.

Figure 2→MaatiSirjana merging into the setting (View from the North East)

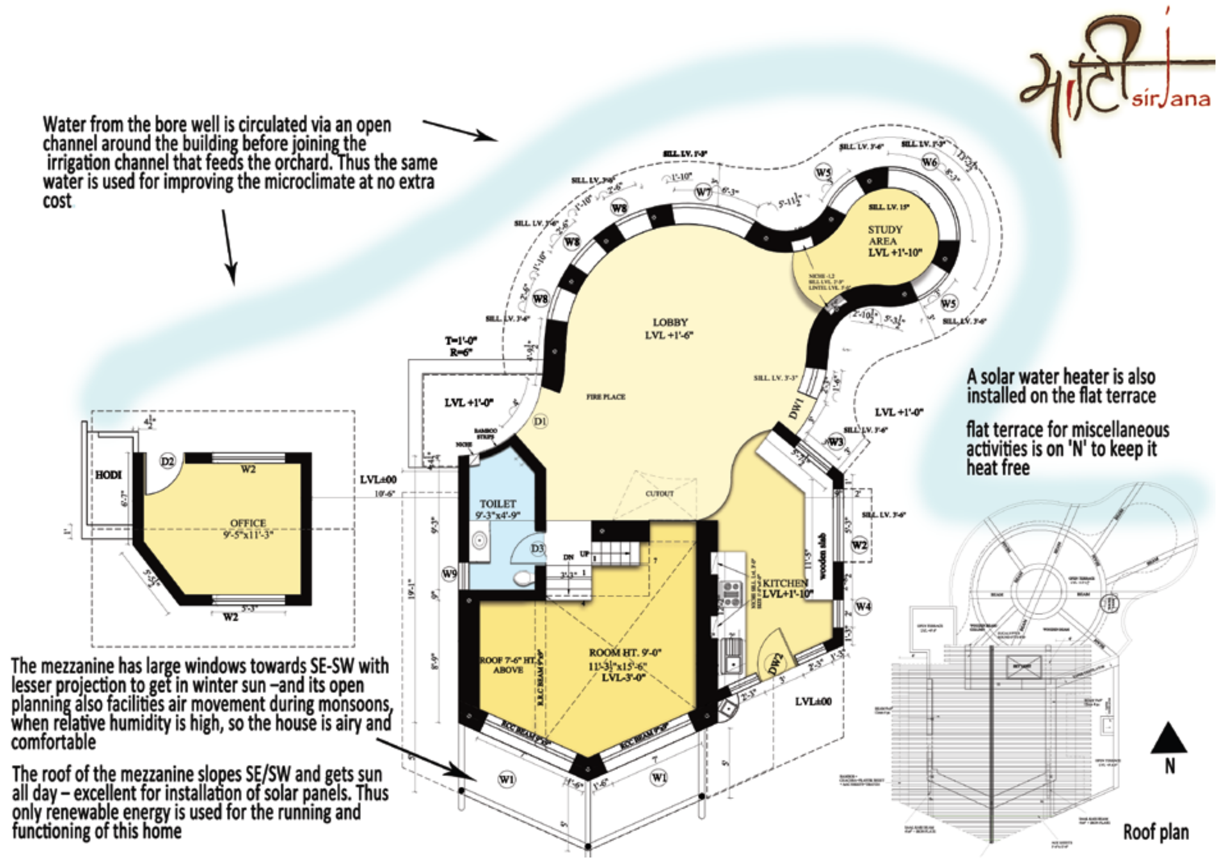

Figure 3 →Floor Plan of MaatiSirjana

Table 1. Advnatages of Space Positioning

Space	Direction/Position	Advantage
Prayer Area	North East	Gets early morning sun
Kitchen	South East	Gets natural light all day and gets morning sun-rays which act as a disinfectant.
Main Bedroom	3’ below ground level	Earth Cooling
Bathrooms	Stacked above one another	Easy Plumbing
	In the West	Traps the heat from the afternoon sun in summer and prevents heating up of rooms.
Windows (Large)	North	Gives heat –free / glare free light
Lobby (Open to the sky)	Center of the building	Improves the energy flow within the building and also cools it in summers
	Openable skylight	Acts as a duct for evaporative cooling in extreme heat and improves air circulation and wind flow.

Materials and Construction

This project showcases the techniques of constructing in mud, bamboo, thatch, terracotta and burnt brick. The age-old techniques have been refined and improvised so as to ensure **longevity, ease of maintenance, cost effectiveness, contemporary demandsviz-a-viz aesthetics and comfort**A lot of research and improvisation was done to reach an optimum solution. The ancient science of vaastu viewed buildings as a whole with man and environment.

Adobe: The typical adobe wall is built on the top of a foundation of concrete block, or stone and mortar, which rises high enough above ground level to eliminate the erosional action of standing water. The tar can be used as a moisture barrier between the concrete block and adobe.A concrete bond beam formed on the top of the last course of adobe ties the wall togethor and supports the roof framing. This works well in moderate and hot climates. Builders of energy–efficent homes often augment these thermal qulities with insulation, particularly in cold climates. Some adobe walls are left exposed, and deep overhangs protect them from moisture.

Construction

The foundation upto plinth level was done in burnt brick. Two steel bars 8mm were used in the plinth beam and junctions to ensure seismic resistance. Also the burnt brick plinth prevents the harmful effect of ground moisture on adobe. During the construction of the foundation, the mud bricks were being made on site by earth dug out. This eliminated the requirement for fuel for transport. Burnt bricks have been used only up to plinth and in service areas as this ensures better plumbing and results in contemporary washrooms –a necessity with the modern–day users.

The structural strength of mud bricks and burnt bricks is carefully utilized with due preference given to the former as they are more sustainable and less energy intensive. Reinforced concrete bands are run above openings as well as plinth to ensure seismic- resistant safety. The structural safety is ensured, while working towards reducing the carbon footprint of the building. For the main lobby area terracotta filler slab is used as it more cost effective and provides better insulation.

A detailed study of the vernacular architecture revealed that the grass grown along the irrigation canal could be used for roofing. This particular weed grass*sarkanda*(Saccharumbengalense) is insect resistant and fire resistant, however, over a period of time, as RCC roof slabs became the norm, the techniques of thatch roofing were hard to find. An extra layer was added for the water proofing, between two layers of thatch. The local labour was thus trained for future use. Not only does the roof cost much lesser, its thermal insulation is far superior and no transport of material was necessary.

Sal rafters, recycled and bought from old homes (being demolished in various parts of the city) are used for the mezzanine floor.All the furniture, fitting, accessories were crafted on site from the waste wood of naturally felled trees on the site. Thus no new wood was used. However 150 new trees were planned in the vicinity to maintain the regenerative process. The plastering of the mud wall has been done in straw, mud, cow dung and adhesive. The resultant wall looks like heritage paint and gives a serene effect. Change in the quality of daylight across seasons makes the experience of mud–plastered walls dynamic. Light may reveal their texture in sharp relief or a mellow tone. As there is a potters village nearby, handmade tiles from the local potters are used in the kitchen and bathrooms. The deck was made out of local eucalyptus and sal wood rafters with bamboo railing. Flooring in mud is done in the living area. Linseed khal was used with mud, clay, cow dung, straw. When rubbed thoroughly it gives a shining mud finish, an excellent floor. Bamboo is used for ceiling treatment, railing and light fixtures.

The underground room and kitchen flooring is in the local "katni" stone Keeping the current day necessity of security, a state of art security system is installed. There is also an inverter power backup and a duct for a desert cooler that cools the entire house at very little cost. All services i.e. electrical, sanitary are by green certified companies –Thus ensuring –***A fusion of traditional techniques and materials with modern necessities.***

OUTCOMES

The house has been in use for a year and half and has seen all season of the Indo-gangetic plains of North India from very severe summers,to heavy rainfall, to extremely cold winters. Just one desert cooler,with a vent through the central duct was sufficient in summers. In June when the temperature outside was 45°C, inside it was 28°C – perfect for human comfort. In winters, the in built fire place was used to burn scrap wood collected from the grove and the temperature inside was 22°C, where outside was 13°C. Openable windows ensured perfect cross–ventilation, trapping the breeze in monsoons and creating Venturi effect, thereby adding to the human comfort.

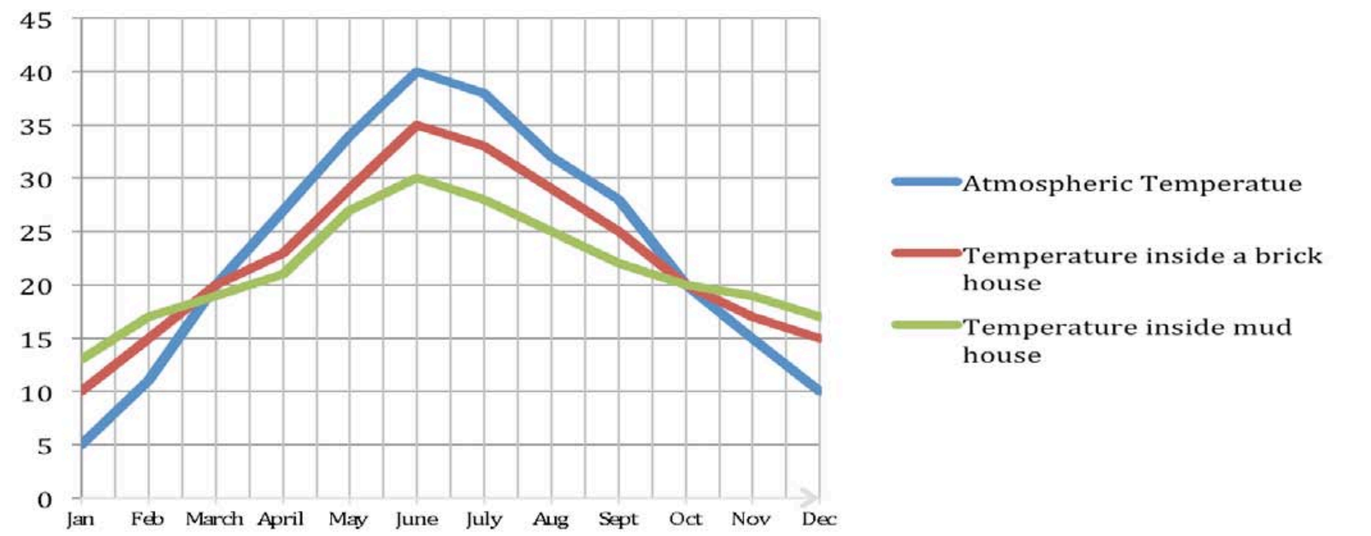

Figure 4 → Graph Showing temperature emulation

Adobe has excellent thermal insulation and accoustical properties. It also filters out harmful radiations and is low cost – ecologically and economically. A house planned according to the solar passive techniques, principle of Vaastu and built in adobe, thatch and filler slab is cost effective and ensures human comfortwithout consuming extra energy.

INFERENCES AND CONCLUSION

We cannot ecologically afford 6-8 air conditioners or the tonnes of steel and cement that go into building an average home when thousands have to be built. Operating on a 12 hour cycle of passive cooling and solar heating, adobe dramatically reduces the reliance on air-conditioning units. In a time of volatile fossil fuel prices, the economic benefits of adobe's natural temperature controls are difficult to ignore.

Smaller towns like Karnal in India, are unbanizing at a great pace, and each individual aspires to own a house. It is estimated that the residential sector in construction is likely to see an unprecedented growth.

If architects and builders were to provide homes like *MaatiSirjana*we could reduce the carbon footprint in this country significantly. Building in mud is seen as building for the poor, if awareness is generated – it could change the mindsets of people in a developing country like India. By reducing a home's environmental footprint a homeowner can lower operating costs. The owner will enjoy increased comfort due to fewer drafts, better humidity control and better indoor air quality, and will benefit from enhanced durability and less maintenance based on the longer-lived components and systems utilized.

T.E.R.I. Testimonial The Energy Research Institute, Delhi has introduced GRIHA, a rating system to judge the "greenness "of building.Swagriha**:** Is the system in which building with covered area less than 2500 sqm is evaluated.

*MaatiSirjana*was submitted for the *Swagriha*rating and was approved by the evaluators. Thus it is ecofriendly, green and low cost.

Figure 5 → View from the South West

ACKNOWLEDGEMENTS

Didi contractor: an architect practicing in the Kangra, attempting to revive thelocal vernacular, was the inspiration.
Thanks to Ar. ChitraVishwanath, Biome, for her guidance.
The author thanks the entire team that worked on MaatiSirjana specially Ar. Kapil Grover and Bani Kaur.

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Session 8C : Building reuse and refurbishment

PLEA2014: Day 3, Thursday, December 18
14:10 - 15:50, Grace - Knowledge Consortium of Gujarat

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A Multi-Stage Approach to Low Carbon Housing Renovations

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ABSTR ACT HEADING

In 2009 the European Union approved "Roadmap 2050" to reduce greenhouse gasses by at least 80% below 1990 levels by 2050. In 2012 the Danish Government established to achieve 100% autonomy from fossil fuels by 2050 by implementing a strategy that included reducing energy demand of existing housing that accounts for about 40% of the national gross energy consumption. A mass retrofit of the existing housing stock could lead to 75% reduction of energy use and carbon emissions. However due to the cost and disruption of retrofits that can radically improve energy performance of buildings, strategies that address both disruption and cost have to be considered. One such potential strategy examined in this paper is a staged approach, which involves different elements of a building to be upgraded over several years, thus spreading the capital cost of the work and enabling the occupants to remain in their homes. Applied to the Danish context this approach can also benefit from financial incentives currently in place. Adopting a case study approach in conjunction with IES modelling, a cost analysis and interviews with industry experts, this research examines the energy savings, capital cost, cost savings of a selection of energy improvements measures, and the implications of undertaking the building work on the occupants of typical Danish detached houses built between 1850-1930. It concludes by proposing a decision matrix for home owners to achieve the most cost-effective and least disruptive approach to undertaking radical energy upgrades.

INTRODUCTION

Background

In 2009 the European Union approved "Roadmap 2050" to reduce greenhouse gasses "by at least 80% below 1990 levels by 2050" (Roadmap 2050). In March 2012 the Danish Government established a new, ambitious Energy Policy, to achieve a 100% autonomy away from fossil fuels by 2050. The strategy adopted to reach such results involves a consistent reduction of the energy demand. According to the Danish Energy Policy Report (Ministry of Climate, Energy and Building, 2012), the existing building stock accounts for about 40% of the total energy consumption; more specifically in 2010 the 69% was related to the housing sector, and the 36% to non-residential buildings (IEA, n.d.; Agency Danish Energy Agency, 2011). Thus, the biggest savings could be achieved by improving the energy performance of the less efficient housing stock. However, this mass-retrofit meets two barriers, involving the government and the private owners: one is financial (Kragh and Rose, 2011, p2252) and

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one is practical (Thorpe, 2010, p.2). The first requires financial help from the government to the private owners, and second one requires a solution to prevent the occupants from moving to a temporary home. A multi-stage or "stepwise" (Galiotto *et al.*, 2012) approach to energy efficient retrofits could address these issues.

Aim of the research

This paper investigated a staged retrofit strategy as feasible solution to finance a national mass retrofit; to make an expensive housing retrofit more financially sustainable and more practical. Smaller and less disruptive works carried out in several stages could distribute the total investment in more than one transaction; they could also allow the occupants to stay in their homes and avoid additional expenses to rent a temporary accommodation.

METHODS

Due to time limitations this research has focused on a specific category of detached houses, built between 1850 and 1930. Detached houses were identified as most diffused and the worst performing housing type; they account for the 52% of the entire housing stock (Statistics Denmark), and for more than 330,000 units (53%) with EPC labels between D and G and a heating consumption requirement above 240 kWh/m^2/yr (Aggerholm *et al.*, 2010)-.

The construction details and materials of the housing type analyzed were sourced from the Danish report for TABULA Project (Wittchen and Kragh, 2012). The reference retrofit measures used were collected from a previous research by SBi, the Danish Building Research Institute (Galiotto *et al.*, 2012), by VTT, the Technical Research Institute of Finland, (Häkkinen *et al*., 2012) and Larsen *et.al* (2011).

IES- VE was chosen as dynamic simulation tool to test the effect of several retrofit measures on the building performance. A 3d model of a real detached house from 1917 and located in Copenhagen was built in IES. It was used an average floor, window and floor area; average construction, materials and shape; the U-values, infiltration rate, boiler type were conformed to those specified in the TABULA project report (Wittchen and Kragh, 2012). The NCM heating, appliances and occupants' profiles were used. The details of the model created and the average building described in TABULA are shown in Table 1.

Table 1. Multi-Stage Plan. Number of Years for Each Stage.

	Average building	Example building	
U-values			Area m^2
Wall	1.6 W/m^{2}K	1.6180 W/m^{2}K	88
Roof	0.6 W/m^{2}K	0.5724 W/m^{2}K	86
Ground Floor	1.5W/m^{2}K	1.6078 W/m^{2}K	47
Windows	2.7W/m^{2}K	2.7 W/m^{2}K	15
Door		2.29 W/m^{2}K	
ACH	0.45	0.45	
Boiler	Old non condens.	Old boiler Ɛ=55%	
Fuel	Oil-gas	Oil - gas	
Area	112 m^2	122 m^2	
Windows area	15.1 m^2	15.1 m^2	
Wall area		88 m^2	
Roof area		86 m^2	
Slab		47 m^2	
Ceiling Height	2.5	2.1 (basement, first floor) 2.7 (ground floor)	
Location	DK	Copenhagen	
Age of construction	1850-1930	1917	
Heating consumption	263 kWh/m^2 yr	265 kWh/m^2 yr	

ANALYSIS

IES modelling

A first series of simulations was carried by introducing one variable at a time in the model's building construction; such as wall, slab or roof insulation, new windows, mechanical ventilation, heating system. All the measures were previously collected from other research. The results were organized in reduction of the heating consumption (%), the reduction of Carbon Emissions (%), the grade of disruptiveness and invasiveness of each measure (low- medium and high). Table 2 shows the percentages of reduction achieved by the measures belonging to the different building's systems.

Table 2. Heating Consumption (%) and CE reduction (%) of the Building's System tested in IES-VE.

Measure	Heating reduction	CE reduction
External wall insulation	51,2%	39,7%
Slab's insulation	16-20%	12-22%
Mechanical ventilation combined with airtightness of 0.15ACH	10%	7%
Windows	5-7%	4-6%
Roof and ceiling insulation	6-8%	4-5%
Heating system	0%	7%

Cost Analysis

In order to identify the most cost-effective and less invasive measures, it was important to compare the costs, the savings and their grade of disruptiveness. The comparison was carried only for wall and slab's insulation as the measures tested varied for thickness, type of material and strategy adopted (internal or external insulation).

The prices were found online, and on Spon's Architects' and Builders' Price Book 2013, available at the University's Library (Langdon, 2013). The Danish prices were available on V&S Prisdata, provided by Byggecentrum, with an annual price. For this reason, the labour prices were searched in Spon's, while the materials‘ costs were found on the sellers' websites (listed in the references), and by asking quotations to the manufacturers.

The external insulation of the wall with demolition of the cavity wall, and cavity insulation + internal insulation were excluded from the feasible measures because highly invasive and disruptive, less effective than the external insulation, and more expensive. Thus, the most cost-effective solutions with the shortest payback period are the insulation of the cavity wall and an additional external insulation, which can be between 50 and 160 mm., as shown in Fig. 2.

As shown in Fig.3 the ceiling insulation seemed to be most cost-effective than the roof insulation because it involves a smaller surface to cover, thus lower material costs, but similar savings to the roof insulation (6% reduction of heating demand in both cases, 4% reduction of CE for 200mm insulation and 5% for 400mm insulation). Also the ceiling insulation can be less disruptive than the roof insulation, which would involve a disassembly of the roof cover and waterproof layer. Such measure is suggested only in case the roof needs to be updated because it would solve a problem of thermal bridging in the junction between the roof and the external wall.

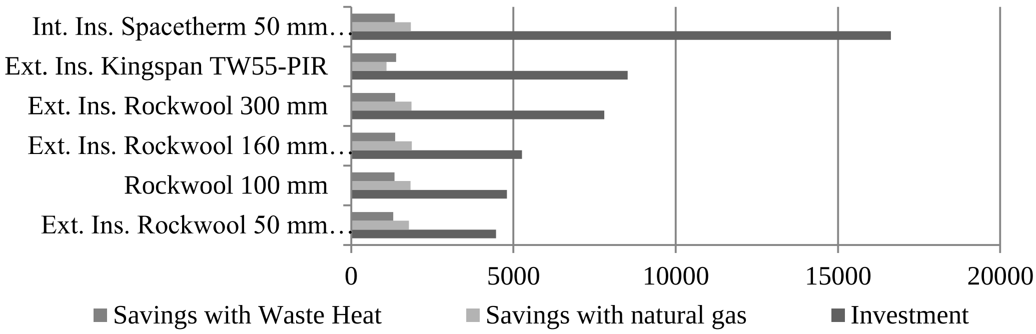

Figure 2 Investment, Saving with Waste Heat and Saving with Natural Gas for Wall Insulation Measures (£).

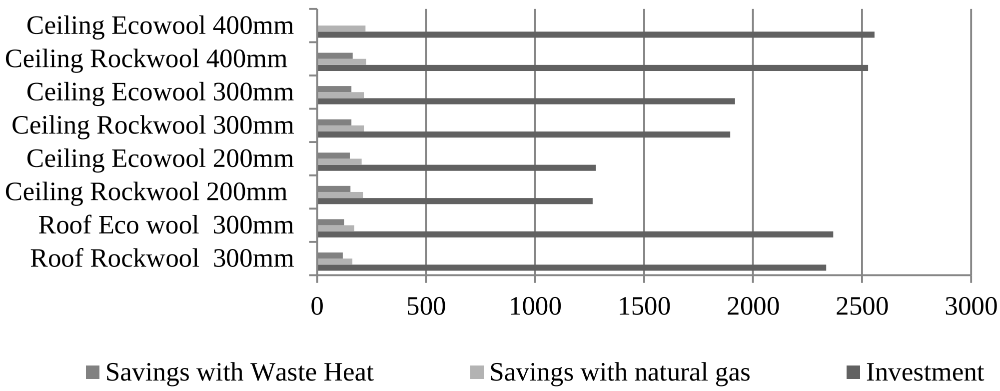

Figure 3 Investment, Saving with Waste Heat and Saving with Natural Gas for Roof and Ceiling Insulation (£).

A second series of simulations was run to estimate how much the heating demand could be reduced, once all the retrofit measures are completed. For this purpose any possible combination of measures was tested. The ACH used were 0.3 (a medium value); in such old leaky houses a value of 0.25 ACH is hardly achievable. Among 127 simulations the heating demand varied from a maximum of 39 kWh/m^2/yr, to a minimum of 20.7 kWh/m^2/yr; both results are lower than the established goal of 44 kWh/m^2/yr (Danish energy class 1).

According to the results of all the IES simulations, the multi stage plan should follow the next order: cavity insulation, external wall insulation, slab insulation, mechanical ventilation, roof and ceiling insulation, windows and heating system.

However these dynamic simulations cannot considerate the fact that the single measures are part of a staged plan and cannot preclude further works in the future (Thorpe, 2010).

Interview

For this reason a semi-structured interview was conducted with a NIRAS' engineer specialized in energy efficient retrofits. During the interview, the installation of an automatic heating control system was recommended as first measure on the list, being a cheap and very effective solution. In fact, further simulations confirmed that.

The time-temperature control and the time control can both lead to a 38% reduction in space heating demand; while the temperature control only a 10% reduction. The carbon emissions were reduced by 31% with the first two controls, and by 9% with the third one.

The engineer also evidenced how changing windows can be a priority for the occupants to enhance the thermal comfort, and avoid air-drafts.

Besides, it was suggested to consider windows and external insulation as a whole package; indeed, if the external insulation is applied first the windows should be moved to the outer layer of the wall to avoid thermal bridges. Thus, the windows could be changed when moved, avoiding extra installation costs.

At last, the mechanical ventilation cannot be considered as measure unless an airtightness test proves that the infiltration rate is lower than 1,5 ACH_{50}.

The limitations of a multi-stage retrofit were also discussed during the interview. Not all the construction details can be solved during a multi-stage retrofit (certain thermal bridges) and these limitations need to be accepted and explained to the owners not to create too high expectations. In fact, the savings obtained by large scale and less expensive retrofit (nearly 80%) can still make a big difference in reducing the gross energy consumption and the CO_2 emissions of a Country.

Multi-stage plan

Based on these suggestions and considerations the final multi-stage plan was organized in 11 stages and the measures of each stage were classified in low-medium and high budget (Table 3), The intent was to produce a flexible scheme that leaves to the single owners the choice of the best measures for their budget.

Table 3. Multi- Stage Retrofit Plan

		Low budget	Medium budget	High budget
1	Automatic heating control	Boiler control	Boiler and time/temperature control	Boiler, time and temperature control
2	Cavity insulation	75mm Phenolic foam	75mm Eco bead Platinum	75mm Bio-foam
3	Windows	Double-glazing 1.25	Double-glazing low-e	Triple glazing
4	External insulation	50mm mineral wool, EPS, PIR	100mm mineral wool, EPS, PIR	160mm mineral wool, EPS, PIR
5	Roof insulation	300mm Rock wool, Ecowool	400mm rock wool, Ecowool	Renovation of the whole roof and placement of 340-400mm insulation on the external side of the roof.
6	Basement insulation	200mm Rockwool, Ecowool, cellulose insulation	300mm Rockwool, Ecowool, cellulose insulation	400mm Rockwool, Ecowool, cellulose insulation
7	Slab insulation	160mm XPS insulation on top of the existing slab	250mm XPS insulation under the new slab	300mm XPS insulation under the new slab
8	Basement insulation	50mm insulation	100mm insulation	
9	Insulation/new external doors	50mm insulation	New insulated doors	
10	MVHR	High efficiency	Most efficient MVHR model	
11	Heating system	Gas boiler	District heating	Ground Source heat pump

The list of measures was accompanied by a scheme, shown in Fig.4, with questions and answers (yes/no) that show which is the first stage to undertake and which should follow. For each stage there is a corresponding color, that remands to the first scheme of measures.

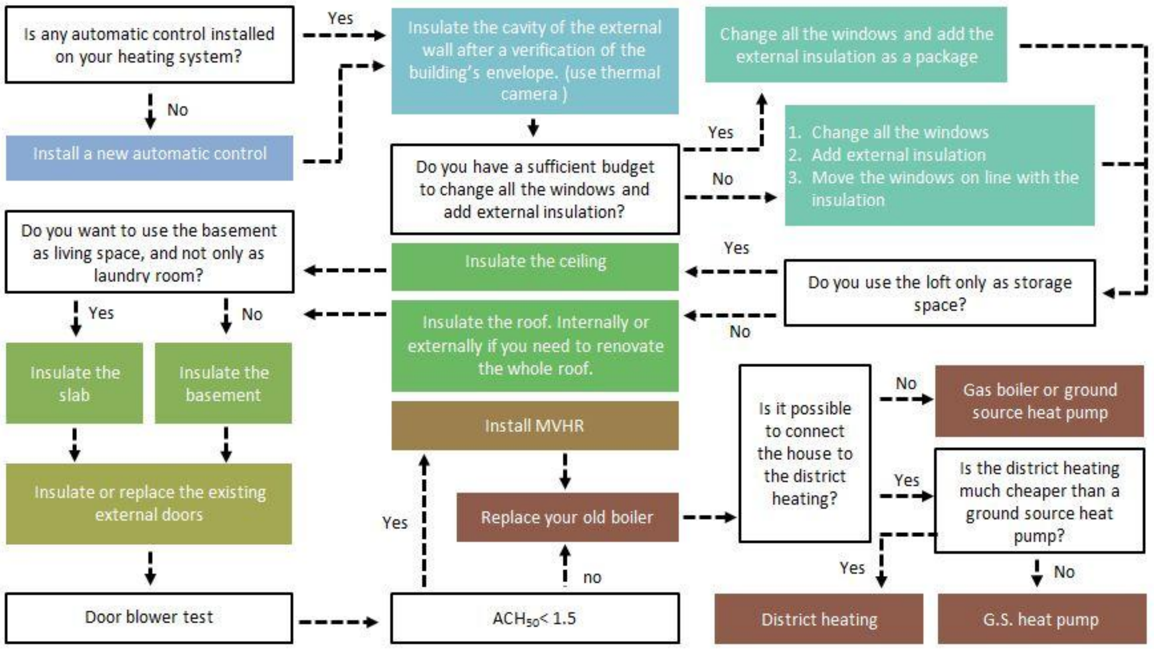

Figure 4 Guiding Scheme to House owners.

Possibilities to finance energy efficient retrofits

If the financing barrier is to be overcome, the annual cost of energy renovation investment should at least be equal to the annual savings on energy (Kragh and Rose, 2011), and at the moment, even with the increased energy price, the payback period for energy retrofits is still too long.

In this research an existing tax deduction was used to abolish or reduce the difference between investments and energy savings as shown below :

$$Annual\ Investment = Annual\ Energy\ Savings + Annual\ "Artisan\ Deduction"$$

The so called "artisan deduction" consists of about £2000 per salary/yr, to deduce for installation and craftsmen costs, but not for materials and devices costs (SKAT), which account for half of the total investment. In this research it is assumed a modification of the tax scheme, allowing the homeowners of a specific category to deduce also materials and devices' costs.

Another assumption is that the annual savings on energy are cumulated and saved in a bank account with exclusive use for the next stage, until the whole retrofit is completed.

In Denmark detached houses are often occupied by one or two families, in which case there could be two, three or four salaries that could bring £3496-£5244 of tax deduction per year/house.

A scheme showing the investment, the energy and carbon savings and the tax deduction for 1,2,3 and 4 salaries was created to verify the workability of the new "artisan deduction" and the cumulated energy savings. The final equation is:

$$Annual\ Investment = \sum_{n-1}^{n} Energy\ Savings\ + \ Artisan\ Deduction$$

n=number of the years since the first retrofit stage

Where the result is negative, the investment is paid back in the same year of realization, through the monetary savings obtained by reducing the energy demand and the incentives. When the difference is positive, the incentives and the monetary savings are lower than the initial investment. In the first case, it could be possible to carry one or more measures during the given year, depending on how much of the incentive is left. In the second case the measures too expensive to be paid in one year, should be carried out in two or more years (i.e. windows can be changed one at a time). Another solution is to wait a couple of years, save the money not spent for heating, and use it to pay in a single shot the works.

In order to estimate the number of years necessary to carry on the whole retrofit, every time the difference was negative, a new calculation was done adding the cost of the next measure and the savings achievable from that. If the difference was still negative the two or more measures could be carried out the same year.

In all cases the first two steps can be completed in one year. The window replacement can require one or two years with one salary, and one year for the other three cases. Only with four salaries per household the windows could be replaced at the same time when adding external insulation. The next steps can be completed in five years with one salary, for a total of seven years, in case the house is connected to the district heating; and twelve years if there is a heat pump. In case the salaries in the house are two, the retrofit could be completed in six-seven years. if there are three salaries four-five years could be enough to complete the retrofit; four with the district heating and five with a heat pump.

Table 1. Multi-Stage Plan. Number of Years for Each Stage.

Year of retrofit	**1 Automatic Control**	**2 Cavity Ins.**	**3 Window**	**4 Ext. Ins.**	**5 Roof Ins.**	**6 Slab**	**7 Door**	**8 MV**	**9 Boiler**	**10 Heating System**
1 salary	Yr 1	Yr 1	Yr 2-3	Yr 4	Yr 5	Yr 5	Yr 5	Yr 6	Yr 7	Yr 7-12
2 sal.	Yr 1	Yr 1	Yr 2	Yr 3	Yr 3	Yr 4	Yr 4	Yr 4	Yr 5	Yr 6-7
3 sal.	Yr 1	Yr 1	Yr 2	Yr 3	Yr 3	Yr 3	Yr 4	Yr 4	Yr 4	Yr 4-6
4 sal.	Yr 1	Yr 1	Yr 2	Yr 2	Yr 3	Yr 3	Yr 3	Yr 4	Yr 4	Yr 4-6

Incentives plan to retrofit the detached houses built between 1851 and 1931 by 2030

Supposing the national mass retrofit starts in 2015 detached houses between 1850 and 1930, all the houses with three or four salaries could be completed in 4-6 years. In 2020 the next stage of the mass retrofitting could start with the houses built between 1961-1972. By 2027 the first stage should be concluded and the 11 % of the whole Danish housing stock retrofitted (Fig.5) with 80% energy reduction. As shown in Fig.69 this group of houses accounts about the 31% of the energy used by detached houses, so the 80% reduction would be equal to 24% reduction of detached-houses' energy use.

CONCLUSIONS

This paper has investigated the possibility of using a multi-stage plan to overcome economic and practicality barriers to energy efficient housing retrofit. The research results have shown that the integration of dynamic simulations and the practical experience of specialists can lead to multi-stage retrofit plans for each housing type.

A financing scheme was proposed to equal the annual investment for retrofit, to the derived energy savings; however, a similar model would be burdensome for the national tax system; which would see the national tax income considerably reduced. On the other hand, without a significant help from the government, only a few house owners would invest their own savings in such housing retrofit, as “one of the main barriers in renovation” is “financing” (Kragh and Rose, 2011, p. 2252).

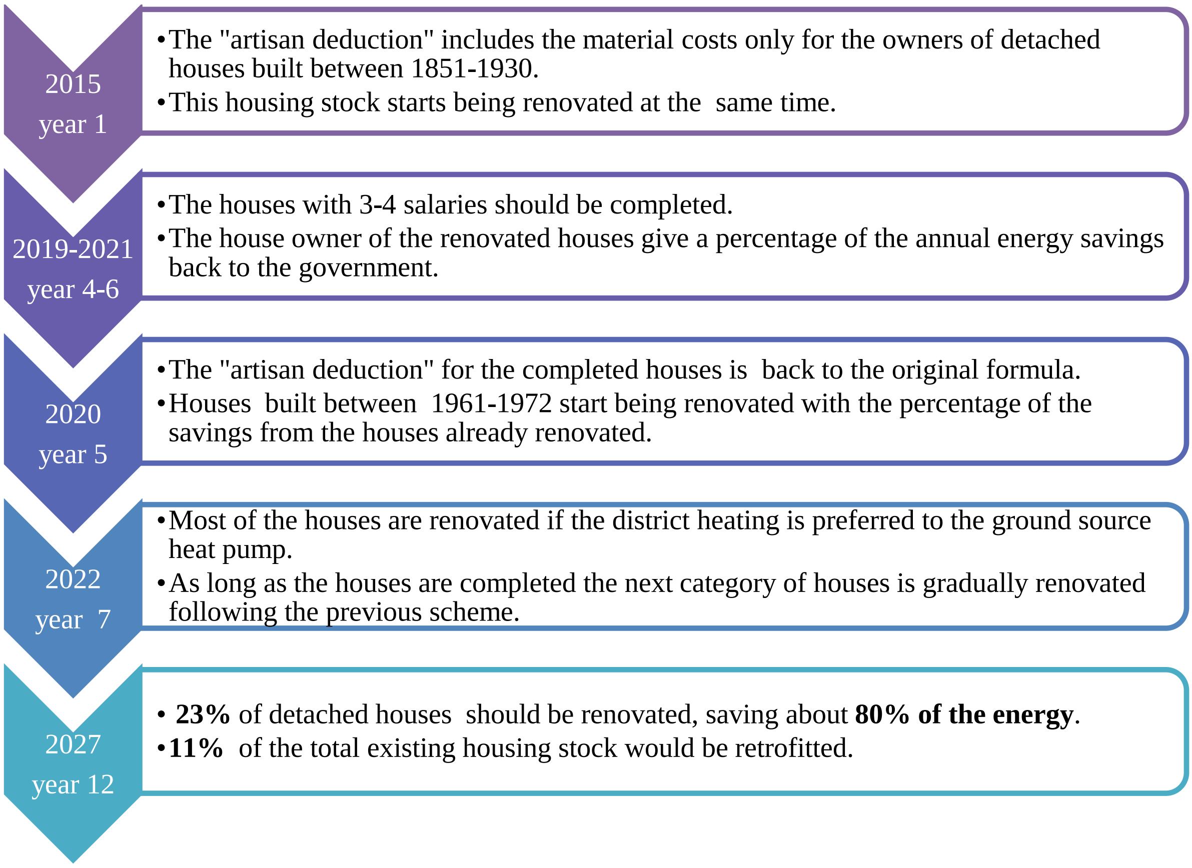

Figure 5 Sample of Mass Retrofit Organization.

Most of them would probably decide to upgrade something, not aware of what they could actually do to have an energy efficient house. In conclusion this research suggests that government guidance is essential as government funding schemes. The proposal of recouping a percentage of the monetary savings achieved by the house holders to help the government to finance the second step could make the scheme unpopular, if the advantages derived from such help are not well stated. Nevertheless, this scheme does not require any investment to the owners, which have only to pay upfront.

Educating the householders about the long term and non-monetary advantages is critical to their acceptance of the scheme. This research has shown how tax-related schemes can encourage retrofit initiatives and how technical solutions can help reduce the cash flow and capital cost. Other technical solutions and financial incentives could address these and other barriers to retrofit initiatives and should be further investigated. In addition, all incentive schemes need to be supported by effective information and this area could also benefit from further research.

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Strategies for an Environment Friendly Low Energy Retrofitting of a Health Care Facility in the Hot Climate of UAE

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ABSTRACT

The existing building stock in the United Arab Emirates finds it more difficult to compete with the new more environmental friendly and energy efficient buildings and do not fit into the country's vision of sustainability. Even if all new building have zero CO2 emissions, the older inefficient building stock will cause the CO2 emissions levels to remain unacceptably high which, means older building stock needs to adapt to environment friendly energy efficient measures. The current research focuses on the green retrofitting strategies of an existing building in the hot and arid climate of the UAE. The study examines the existing building envelope of Latifa hospital using the energy simulation software e-QUEST. Using the simulation model, the building behavior was predicted for the retrofitting strategies of thermal insulations, window to wall ratios, wind types, ventilation fans and types of HVAC system to achieve optimal retrofitting of the building.

INTRODUCTION

For the last forty years, the United Arab Emirates (UAE) has witnessed an unprecedented pace of urbanization and population growth due to rapid economic development. The rapid growth of UAE's economy has been accompanied by a substantial increase in energy consumption. Partly, the significant increase in energy consumption is due to inefficient existing facilities (Elgendy, 2010a, 2010b). The UAE energy intensive construction approach coupled with its extreme hot climate , require heavy cooling and have appointed the UAE in the top 10 countries in terms of electricity usage per capita and the second highest in terms of CO2 emissions per capita (AlNaqbi et al, 2012a, 2012b, AlAwadhi, 2013). The single largest contribution to the electrical load comes from cooling which accounts for an average of 40% of total year around electrical load and up to 60% of the peak electrical load during the summer time (Al Awadhi, 2013). The majorities of UAE buildings stock was constructed long before the introduction to sustainability codes and standards and therefore is incompatible with current standards or the expectations of the users (Shady, 2010). Sustainable retrofit is not a new concept but is gaining recognition and importance owing to current concerns about intensive energy use in buildings leading to climate change (Backer, 2009).

Latifa Hospital (previously Al Wasl Hospital), a 367-bed specialized maternity and paediatric hospital, opened in 1986. The two-story hospital building is oriented east south-east (Figure1) and has a gross floor area of approximately 73,213 sq.m with the central plant area being around approximately 3,300 sq.m (Figures 2, 3).

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Figure 1: *Case study; Latifa Hospital: Massing and Orientation*

The building has a reinforced concrete structural frame with foundations on piles and block work for the external envelope and internal partitions. The base structural bays are 7.20m x 7.20m for a 4.5 floor-to-floor height. Ceilings are set at 3 meters, except in wet areas where they are at a standard 2.70 meters. The external walls are made of a double block work with a 40 mm cavity filled with a pre-compressed isolation polystyrene board and a layer of bituminized fiber for dampproofing. The windows and doors are provided with sealed double glass with solar control coating to regulate the UV light and reduce heat gain while providing sufficient and uniform daylight. Double glazing windows are the common hospital window type, solar control reflective insulating glass type, and bronze color, 6 mm. with direct transmittance 21%, total solar transmittance 26%; shading coefficient 0.30% and U value 1.4 w/m2. K.

METHODOLOGY

In order to develop effective energy conservation guidelines, the nature and magnitude of the energy usage in the existing hospital was determined through direct collaboration with the hospital facility personnel.

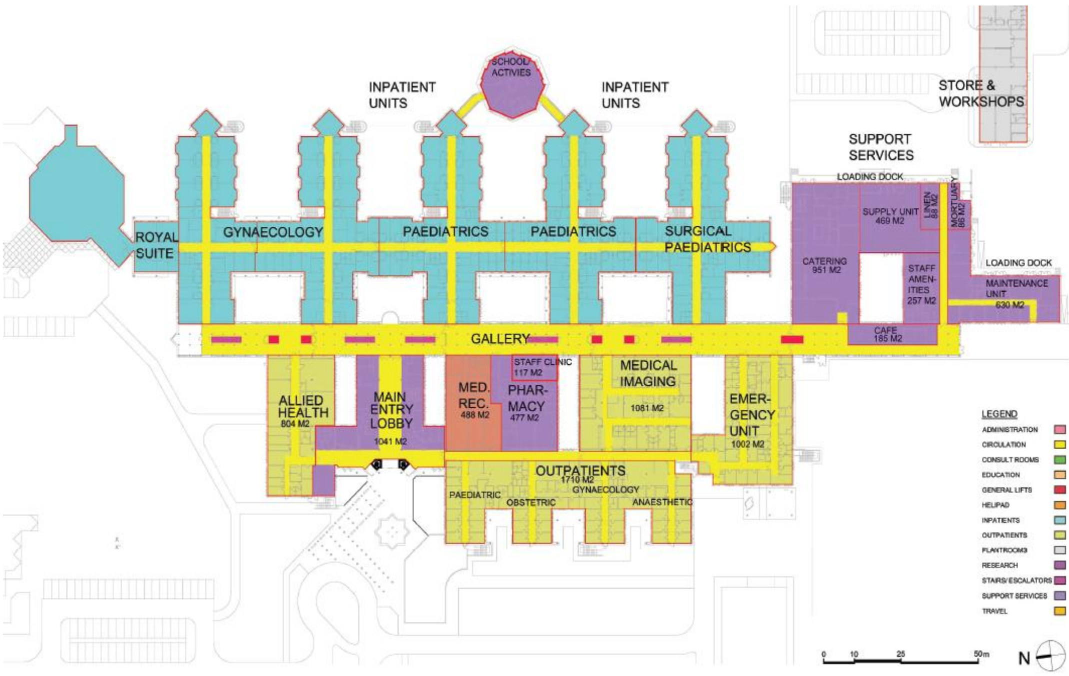

Figure 2: *Ground Floor Zones Layout*

The study investigates the performance of the existing building envelope, the HVAC system and other energy efficiency measures then explores their optimization potential. The inputs for simulation program are collected through extensive review of design drawings.

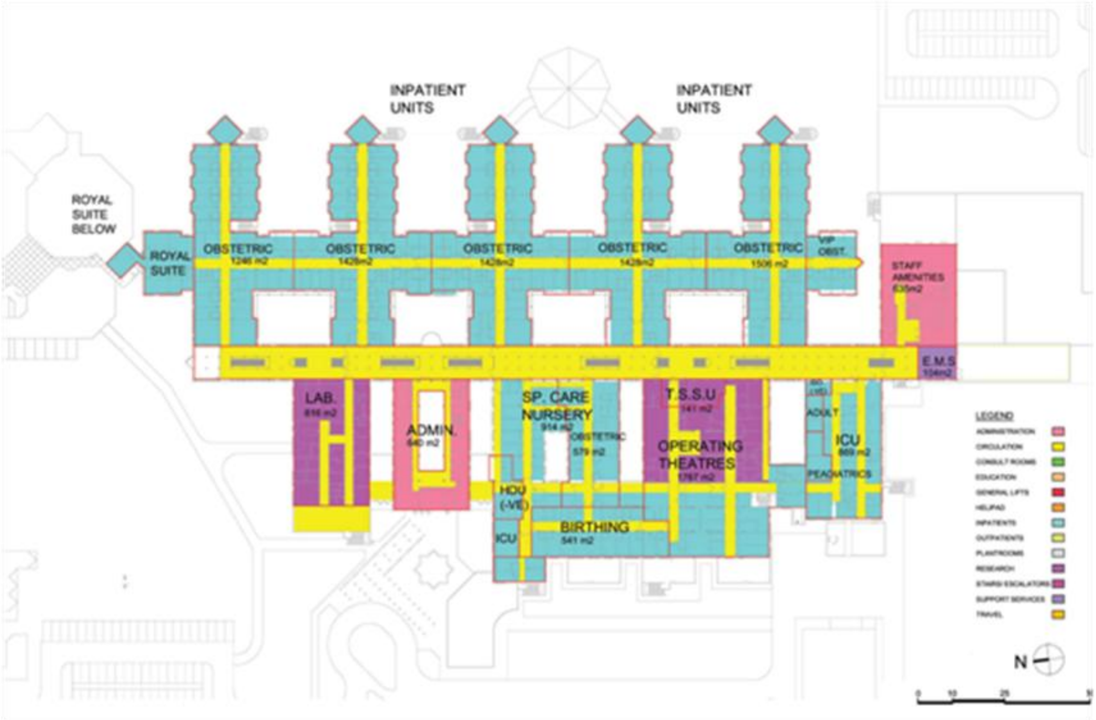

Figure 3: *First Floor Zones Layout*

All the collected data has been analyzed to determine the base case of the existing building electrical consumption and compared with the predictions of the simulations to validate the methodology. The existing building model was generated using e-QUEST software. The building was set at its actual orientation with all openings placed per their location and specificities. As a first step, the building was simulated "as is" to determine the base case. All required inputs of insulation level, type of window and glazing, shading, roof insulation, flooring construction materials, type of HVAC systems, building occupancy, operation schedules and loads were added to the program to calculate the annual energy consumption of the base case. Results obtained from the simulation (e-QUEST) software were compared with the actual energy consumption data achieved through bills and energy audit to validate the simulations results. Once the model was validated, the optimization was carried out to determine potential areas of energy savings pertinent to rerofitting.

RESULTS AND DISCUSSION

Various strategies for energy performance optimizations were tested through simulations. The energy performance simulations were performed through eQuest, in order to optimize the envelope for reduced heat gain through inulations, façade construction, envelop colour and glazings. The HVAC system was optimized for ventilation and infiltration, efficiency rating, better comfort settings and better HVAC scheduling. Thereafter based on the results and analysis, recommendations for retrofitting the building are outlined for façade construction and systems integration.

Wall Optimization

At first, the wall colour was studied for its impact on energy performance of the building to attain an optimum wall colour with reasonable energy performance assuming the darker colour as a reference and with no insulation applied. ~~Walls~~ colors were changed from dark abs.=0.9 to light abs.= 0.4 gradually and the electrical energy consumption was computed. The result shows that change in the walls color from dark to deer' light (abs= 0.45) has reduced annual energy consumption by 0.13% (Figure 4). As a second measure, the effect of wall insulation was studied on the enrgy perfroamce while changing the insulation gradually from R= 0 to R= 12. The increased insulation yielded a reduction in annual energy consumption of 0.33%. Finally the net effect of reduced colour absorptance and increased insulation was simulated which yielded an energy saving of 0.4 %.

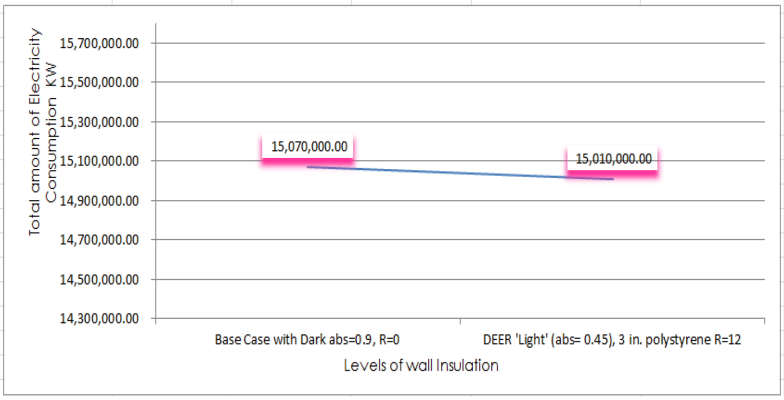

Figure 4: *Simulation results of collective wall optimization through wall colour and added insulation for Latifa Hospital, Dubai using 2013 weather data.*

Roof Optimization

The building roof was optimized following the same scheme described for wall optimization and the individual impact of color and insulation were studied at first while later the combined effect of reduced color absorptance and increased insulation were computed. Change in roof color from dark (abs.= 0.9) to deer light (abs.= 0.4) yielded a reduction in annual electrical energy consumption of 1.81 % plotted (Figure 5). It was observed that the optimum reduction of 2.59% is achieved at R=9 while the drop in energy consumption at higher R-value is insignificant.

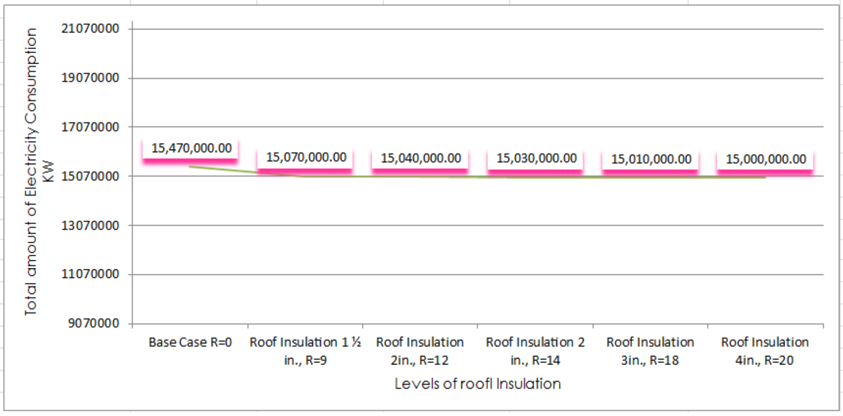

Figure 5: *Simulation results applying roof insulation for Latifa Hospital, Dubai using2013 weather data.*

Envelop Optimization

It was observed that changing the whole envelop color from dark to deer' light (abs = 0.4) yielded a reduction of 2.0% in annual energy consumption while increasing the envelop insulation from R=0 to R=9 resulted in a 3.41% decrease in annual energy consumption. Finally energy consumption for existing envelop insulation values (Wall Insulation R= 6 and Roof Insulation R=6) was simulated and compared with energy consumption of proposed insulation (wall insulation R=9 and roof insulation R=9) which achieved a further reduction of 1.93% compared to the existing insulation level which emphasized the need for retrofitting and replacing the wall and roof insulation. One very important observation writes the stronger impact of color yielding 2 % decrease in annual energy consumption compared to the darker color, an option that carries minimal cost and would be an economically attractive option for retrofits and new designs.

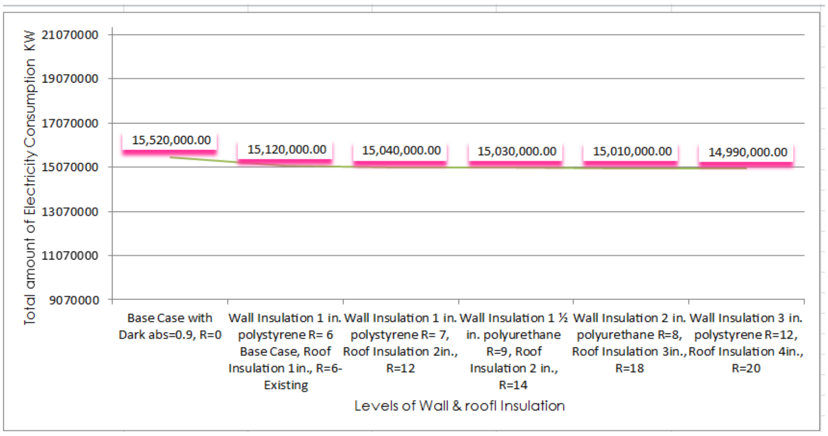

Figure 6: *Simulation results applying façade insulation for Latifa Hospital, Dubai using 2013 weather data.*

Comparing the existing façade colour for retrofitting (wall abs=0.6 and roof abs.=0.4) to the proposed façade colour (wall abs.=0.4 and roof abs.=0.4) yields a reduction of 0.1% in annual energy consumption which indicates that the current façade colour is optimized and offers least opportunities for further energy savings.

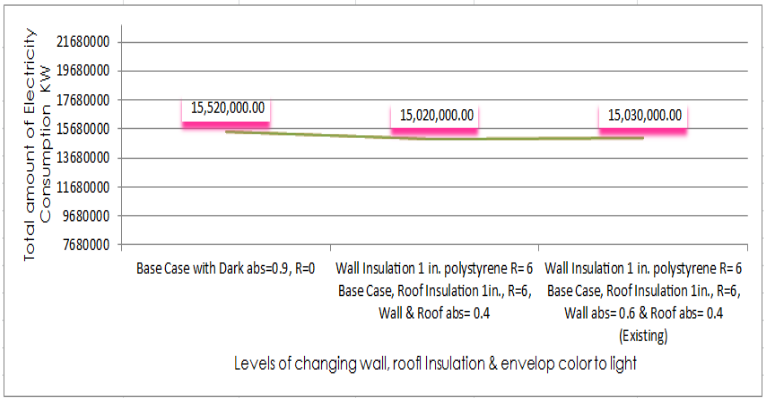

Figure 7: *Simulation results investigating façade colour for Latifa Hospital, Dubai using 2013 weather data.*

Window Optimization

Proper placement of windows and optimized window to wall ratio achieves have a strong impact on energy consumption in the climatic context (Fathy, 1986). In order to optimize window to wall ratio

(WWR), it was increased from a minimal of 10 % to relatively higher value of 45 % and a discrete energy performacne trend was observed in three differenct WWR regimes. In the first regime, increasing WWR from 10.5 to 20 % has negligible increase in energy consumption primarily because the increase in heat gain is compensated by the decrease in area lighting load of the indoors. In the second regime increasing WWR from 20% -30% increased the energy consumption modestly which shows that the benefit of increased ligitng loads are being outclassed by the increase in heat gain. In the third regime, increasing WWR beyond 30 % yielded a sharp increase in energy consumption which indicated that at this stage only heat gain is the consequencial for the increasd WWR which emphasizes economic implications of increasd WWR beyond a certain range. The simulated results agree with similar research which recommends WWR of 10-20% for better energy performance [Aboulnaga, 2006]. Comparing the optimum range of WWR of 20-30 % computed through simulations with the existing building WWR of 17 %, it is proposed that for retrofitting the glazings should be increasd up to 25 % to have better daylight for a healthier indoor climate critical for hospital buildings even at the cost of affordable extra energy consumption.. At the second stage different window types were simulated and it was observed that replacing the existing double clear/ tint glass type to double low-e a reduction of 0.7 % in energy can be achieved which shows that while retrofitting, the window type needs to be re-considered..

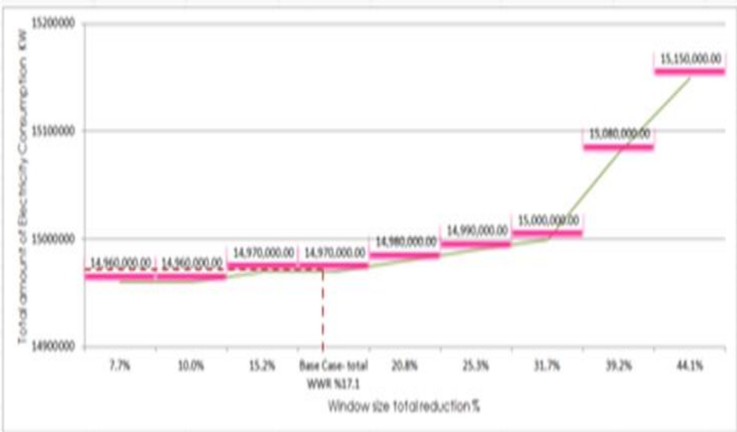

Figure 8: *Simulation results with various WWR for Latifa Hospital, Dubai using 2013 weather data.*

Optimizing HVAC

Energy Efficiency Ratios (EER) of the HVAC was studied against energy consumption in the ange of EER =10 to EER= 26 shown in figure 9.

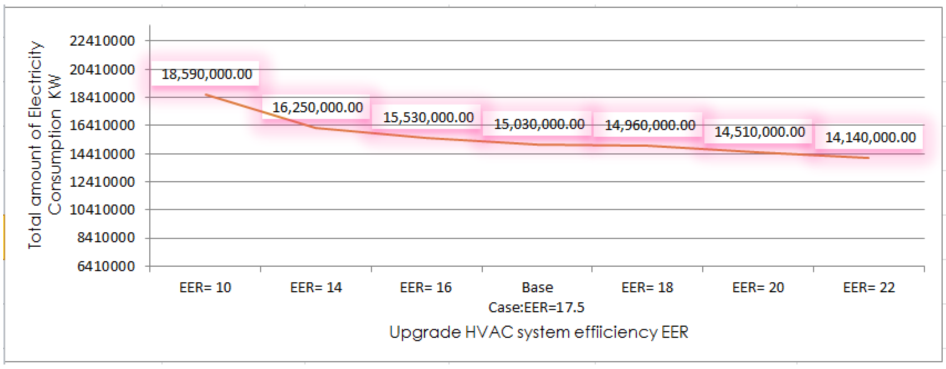

Figure 9: *Simulation results for cooling system energy efficiency for Latifa Hospital, Dubai using 2013 weather data.*

The existing EER of the system being 17.5 was compared with a higher EER value of upto 26 and it is observed that energy consumption can be reduced by 5.92% while increasing the EER to 22. It is therefor emphasized that selecting a higher efficiency cooling system can save a huge amount of energy and the cooling system should be replaced with more efficient system while retrofitting.

Optimizing Comfort Conditions

A general observation made in UAE is a trend of setting thermostate to undesirably (and at times uncomfortably) low temperatures around 20-22 °C which has its implications on energy consumption and oprations cost. Effective and comfortable cooling can still be achieved keeping the thermostat set point at a higher temperature and increasing a little more fan ventilation. An attempt was made to simulate the trend of the impact while changing the thermostate set-point from 22 °C to 24 °C in occupied areas and from 26 °C to 28°C in unoccupied areas being still in the comfort zone based on psychometrics of the place. The result shows a reduction of 0.27% in annual energy consumption which emphasized the importance of operating the cooling system at right comfort conditions without sacrificing comfort.

Optimizing Fan Type

Installing Variable Frequency Drives (VFDs) on the supply and return fans of the Air Handling Unit (AHU) can reduce energy consumption by 20% (Schneider Electric, 2006). In order to test this, the existing constant-volume air handling system with centrifugal fan type was replaced VFDs on the supply and return ducts of the AHUs. The results show a reduction of 20.23% in the annual energy consumption. Although the simulation result showed a substantial potential reduction in energy consumption, this type of fans cannot be used in the hospital environment as the variable VFD causes ventilation problem in low cooling load conditions and causes associated health hazard. It is therefore proposed to keep the same fan type.

Integration of Solar Thermal Collectors

The hospital has a 12,000 lit/day hot water consumption which demands a large amount of energy for water heating. Since UAE has vast solar energy potential, heating problem was solved by integrating solar thermal collector on the roof to provide hot water. The system consists of 18 collecotrs with aperture area of 1.87 m^2, water mass flow rate of 35 kg/hr and water tank capacity of 300 lit each. It is coupled with an auxiliary electrical heating system to constantly supply hot water at 63 °C.

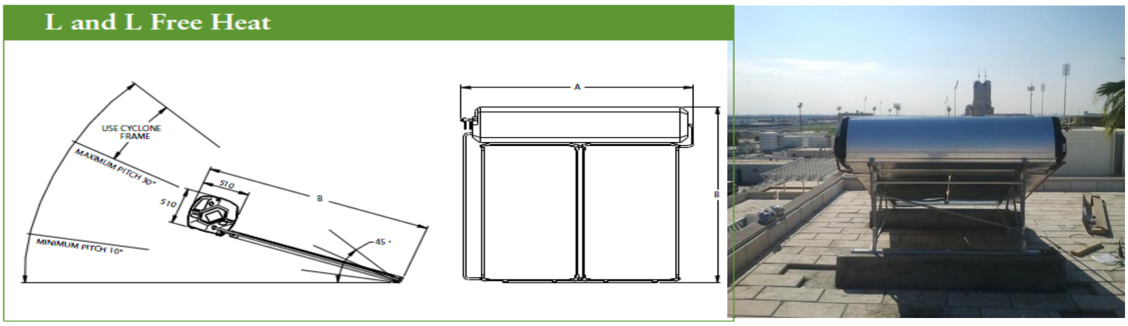

Figure 10 *Solar Thermal Collector installed on the roof of Latifa Hospital, Dubai.*

In order to determine its performance, the solar thermal system is simulated in TRNSYS softwate using

Dubai weather data to find out the ratio of solar thermal energy supplied to the auxiliary energy needed for the stable 63 °C supplywater temperature. The solar thermal system attained a total yearly thermal energy production of 212,224 KWh which contributed 46 % of the total energy consumption for hot water production in the hospital and therefore it is recommended that the share of solar thermal should further be increased to attain energy efficient and cost competitive hot water production.

CONCLUSION

This paper has explored energy saving opportunities while retrofitting an existing healthcare facility in Dubai, UAE through a simulation scheme. The simulations findings resulted in a number of recommendations for energy efficient and cost competitive retrofitting solutions in the climatic context while pointing out indicative impact of occupants' behavior on energy consumption of cooling system.

The findings are in three different areas. First, for the façade construction, choosing a lighter color has huge impact reaching up to 2 % energy savings with least cost incurred, adding wall and roof insulation yields up to 3.4 % energy savings although they incur additional cost as well, proper window type can yield up to 0.7 % of energy savings with minimal cost addition and the optimum WWR is a found between 20-25 % for healthier indoors with little extra energy cost. Secondly for HVAC system operation and efficiency, keeping the cooling set points within acceptable comfort can achieve 0.27 % energy savings with no extra cost and replacing the existing HVAC with a more efficient cooling system can achieve up to 5.9 % energy savings with extra cost of system. Finally integration of 18 solar thermal collectors in the building as a means of renewable and environmental friendly source of energy contributed to 46% energy saving for hot water production economically competitive rates and therefore is recommended for a higher energy share.

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Relating Sustainability Indicators to the Refurbishment of the Existing Building Stock

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ABSTRACT

The construction sector and the associated built environment have an oversized footprint. They are responsible for more than a third of global resource consumption and an estimated 40% of the total waste generation, contribute up to 30% of global annual greenhouse gas emissions and consume a third of all energy. The retention, rehabilitation and reuse of the existing building stock play a pivotal role in the sustainable development of the city. However, there is an ongoing debate on evidencing the sustainability of refurbishment in contrast to demolition and new construction. On the one hand, a newly constructed building can achieve higher operating energy efficiency on the short term, on the other hand, when looking at lifespan, material use and waste generation, re-use or continued use of the buildings is more environmentally sustainable than to demolish and replace them. This paper provides a review of the role of sustainability in the built environment and reflects on this from the perspective of refurbishment; revealing the state of the art regarding the definitions of sustainability, the sustainability legislation on different scale levels and the assessment methods used to certify sustainable buildings. Subsequently, these different aspects will be put in relation to each other and assessed from the perspective of refurbishment.

INTRODUCTION

The construction sector and the associated built environment consume significant quantities of resources and energy, contribute to climate change, and affect the health and well-being of building users and others (Todd, 2012). In 2011 the United Nations Environment Program (UNEP) and the Sustainable Buildings and Climate Initiative (SBCI) released a report (United Nations Environment Programme, 2011) that notes:

1. The built environment is the single largest contributor to global greenhouse gas emissions (GHG), with approximately one third of global energy end use taking place in the operational use of buildings.
2. The construction sector is responsible for more than a third of global resource consumption, including 12% of all fresh water use, and contributes 40% of the generation of solid waste.
3. Constructing new green buildings and retrofitting existing energy- and resource- intensive

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buildings stock can achieve savings of about one-third in energy consumption in buildings worldwide and significantly contribute in the reduction of CO_2 emissions.

4. Greening buildings will bring significant health and productivity benefits.

It is made clear that interventions are not only necessary, but possible. According to Petersdorff et al (Petersdorff, Boermans, & Harnisch, 2006), the main energy and CO_2 saving potential lies in the existing building stock. Most developed countries have regulations consisting of national performance standards for newly built houses. The demolition rate in the building stock can be estimated to be ~½–1%, whereas new constructions to be 1% of the total living area per year, thus resulting in a slight increase of the existing building stock (Petersdorff e.a., 2006). Research in the UK (Power, 2008) suggests that even with ambitious new building programs and a high demolition rate, only 10% of the current stock will have been demolished by 2050, arguing the urgent need to upgrade the existing stock on the grounds that 70% of all homes that will exist in 2050 are already built. Consequently, existing buildings must be sustainably refurbished (Häkkinen, 2007),(Sev, 2011), minimizing the operational energy use while taking into account other sustainability aspects. This paper provides a review of the role of sustainability in the built environment and reflects on this from the perspective of refurbishment. Revealing the state of the art regarding the definitions of sustainability, the sustainability legislation on different scale levels and the assessment methods used to certify sustainable buildings. Subsequently these different aspects will be put in relation to each other and assessed from the perspective of refurbishment.

DEFINITION

In today's world, the term sustainable development is everywhere; over 500 definitions of sustainability and sustainable development have been spawned by various governments, professional bodies, institutions and organizations (Shah, 2012). The growth of sustainable awareness dates back many decades; from Silent Spring written by Rachel Carson (Carson, 2002) and first published in 1962, describing a world affected by pesticides and chemicals, through to James Lovelock's Gaia (Lovelock, 2000), first published in 1969, stating the role of 'mother earth'. One of the first definitions of sustainable development was made in 'Our common future', the report of the Brundtland Commission, calling for development "that meets the needs of the present without compromising the ability of future generations to meet their own needs"(World Commission on Environment and Development, 1987). Whilst this definition is still used today, a more commonly known terminology encompasses the environmental, social and economic principles captured as the 'triple bottom line' (Elkington, 1998), also referred to as the three P's; Planet, People, Profit.

The definitions of the terms 'sustainable building' and 'building sustainability performance' vary according to different actors of the construction industry. The internationally standard definition of a green building is provided by ASTM Standard E2114–04 (E06 Committee, 2004), that is, "a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life". Furthermore, "a green building optimizes efficiencies in resource management and operational performance and minimizes risks, which threaten the human health and environment". By emphasizing performance requirements and human health, the principles of the triple bottom line are integrated within this definition of a green building. Also, it specifically mentions the importance of taking into account the different stages of a buildings lifespan, from construction and service lifespan, to what happens after a buildings service lifespan.

LEGISLATION

Worldwide Legislation

The United Nations Framework Convention on Climate Change (UNFCCC) was negotiated at "the

Earth Summit", the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. The objective of this international environmental treaty is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The Kyoto Protocol is an international agreement linked to the UNFCCC, which commits its Parties by setting internationally binding emission reduction targets. The main goal of the Kyoto Protocol is to contain emissions of the main anthropogenic (i.e., human-emitted) greenhouse gases (GHGs) in ways that reflect underlying national differences in GHG emissions, wealth, and capacity to make the reductions. The first round of the protocol was completed in 2012, but much greater emission reductions will be required in future to stabilize atmospheric GHG concentrations (Oberthür & Ott, 1999).

European Legislation

For meeting the commitments on climate change made under the Kyoto protocol, the EU has introduced legislation to ensure that buildings will consume less energy in the future. A key part of this legislation is the Energy Performance of Buildings Directives (EPBD). The first directive (Directive 2002/91/EC,EPBD), first published in 2002, requires that an energy performance certificate (EPC) is made available when buildings are constructed, sold or rented out. The certificate has to express the operational energy performance of the building. Also, every country had to insert legislation stating a minimum performance. Subsequently, the second Directive (Directive 2010/31/EU, EPBD) states, that "Measures are needed to increase the number of buildings which not only fulfil current minimum energy performance requirements, but are also more energy efficient, thereby reducing both operational energy consumption and carbon dioxide emissions. For this purpose Member States should draw up national plans for increasing the number of nearly zero-energy buildings and regularly report such plans to the Commission". Also, being more specific, Article 9 states: "Member States shall ensure that: by 31 December 2020, all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings".

There are only very limited mandatory requirements related to building components and materials used in buildings, in practice energy-saving measures predominate. The mandatory requirements that currently exist in the EU countries studied by Reijnders & Van Roekel (Reijnders & van Roekel, 1999) deal only with very limited aspects of the interactions between buildings and the environment.

ASSESSMENT METHODS

As mentioned, an Energy Performance Certificate is obligated in Europe when a building is constructed, sold or rented out, therefore this type of certificate will be considered first. Subsequently, a wider range of building environmental assessment (BEA) tools, which are all voluntary and motivational in their application, will be considered. The field of BEA has matured remarkably since the introduction of the UK Building Research Establishment Environmental Assessment Method (BREEAM) in 1990, and the interim period witnessed a rapid increase in the number of tools (Cole, 2005). Reijnders and van Roekel (Reijnders & van Roekel, 1999) have made a rough division of BEA tools into two groups. The first group includes those, which are based on scores and a criteria system and are regarded as qualitative tools, the Criteria Based Tools (CBT). The second group includes the tools that use life cycle assessment (LCA) methodology with quantitative input and output data on flows of material and energy throughout the different stages of a buildings life cycle, from construction and use to demolition and recycling. For each category, the EPC, CBT and LCA, firstly the sustainability criteria and methodology will be introduced, secondly the pros and cons of their application will be elaborated, and thirdly they will be assessed from the perspective of refurbishment.

Energy Performance Certificate

Criteria & Method. The definition of the energy performance of a building is the amount of energy, actually consumed or estimated, necessary to meet the performance requirements associated with a standardized operational use of the building (Poel, van Cruchten, & Balaras, 2007). The criteria that are used in these calculations are: insulation values, technical and installation characteristics (including own-energy generation), design and positioning in relation to climatic aspects, solar exposure (taking into account the influence of neighbouring structures), and indoor climate factors that influence the energy demand. The Energy Performance Certificate is a document that indicates the operational energy performance of a building as a numerical output, calculated according to a methodology based on the general framework set out by the EPBD. Following the first EU directive, all EU countries have stated a minimum performance. There are many different software programs that allow these calculations to be made, most programs use an interactive model where the user can easily adjust for example the R-value (thermal resistance) of a wall, the type of ventilation system used or whether there are solar panels on the roof or not. These changes immediately result in a change in the Energy Performance, allowing for the user to compare the effect that different options have on the energy use of the building.

Pros & Cons. An EPC is based on the quantitative calculation of the operational energy consumption, creating an objective basis to assess and compare design solutions and buildings. These programs are relatively easy to use and allow for the user to integrate the outcomes at an early stage of the design process. Also, a study by Ronan Lyons (2013) has shown a positive impact of the Energy Performance Certificate on sales and rental prices of buildings on average in most of the Member States that were analysed, indicating that better energy efficiency is rewarded in the market. On the down side an EPC only covers the operational energy use of a building, disregarding not only the stages of construction, maintenance and eventual demolition and recycling, but also the resources that are being used and the environmental impacts that are related with them.

Refurbishment. Energy Performance Certificates are also applicable to existing dwellings and refurbishment projects. Although, since an EPC focusses on operational energy use and doesn't take into account sustainability factors like resource use and waste production, it could be considered easier to attain the best EPC rating th rough demolition and new construction rather than through refurbishment of an existing building.

Criteria Based Tools.

Criteria & Method. The Criteria Based Tools essentially consist of lists of suggestions for the environmental improvement of buildings linked with a score (Reijnders & van Roekel, 1999). Among the criteria-based tools (CBT) are Building Research Establishment's Environmental Assessment Method (BREEAM) and Civil Engineering Environmental Quality Assessment and Award System (CEEQUAL) (UK), SBTool (International), Leadership in Energy and Environmental Design (LEED) (USA), High Environmental Quality certification (HQE) (France), EcoProfile (Norway), PromisE (Finland), Green Mark for Buildings (Singapore), H K-BEAM and CEPAS (Hong Kong), Green Star (Australia). BREEAM is the leading and most widely used criteria based environmental assessment method for buildings (Nguyen & Altan, 2011). It was developed in the UK in 1990 and is the building environmental assessment method with the longest track record. The CBT's cover a wide range of criteria which are classified into categories (e.g. BREEAM): Energy, Transport, Water, Waste, Materials, Land Use & Ecology, Health and Wellbeing, Pollution, Management, Innovation. The method of a CBT typically consists of three major components (Cole, 2003).

1. Structure; a declared set of environmental performance criteria organized in categories.
2. Scoring; the assignment of a number of possible points or credits for each performance issue that can be earned by meeting a given level of performance.
3. Output; a means of showing the overall score of the environmental performance of a building or facility, usually involving a weighting system that is assigned to the different categories.

Pros & Cons. The Criteria Based Tools offer a wide range of sustainability aspects; there are even credits to be earned considering whether there is a bus stop nearby or not. On the downside, the coverage is rather superficial (Reijnders & van Roekel, 1999) and is not based on a systematic study of environmental impact related to the factors concerned; it is unclear whether the effects of the environmental improvements suggested are marginal, substantial or large (Reijnders & van Roekel, 1999). Additionally, weighting is inherent to the systems and when not explicitly, all criteria are given equal weights (Todd et al., 2001). According to Lee et al. (2002) weighting is the heart of all assessment schemes since it will dominate the overall performance score of the building being assessed. However, there is still no consensus on the assignment of weightings. The Green Building Challenge aims to provide a default weighting system, taking into account regional differences by encouraging users to change the weights. However, although sustainability issues differ from region to region, there is no consensus on regional weighting systems. There is a concern that it is possible to manipulate the results, if the default weighting system is altered in order to satisfy specific purposes (Larsson, 1999;Todd et al., 2001)(Ding, 2008).

The Criteria Based Tools are very complex, it requires training and certification to be able to use them (Nguyen & Altan, 2011). As a result, they are not accessible and are often used as a checklist at the end of the design stage instead of being used early in the design process while the most important decisions with regard to sustainability should be made at the beginning of the design process (Zeiler, 2011). Environmental issues are broad and difficult to capture, combining qualitative and quantitative data, a balance between completeness of coverage and ease of use remains one of the challenges in developing an environmental building assessment tool (Ding, 2008).

Lastly, developers and designers use the CBT's to attain an overall desired "score": a BREEAM "Excellent" or "Very Good," or LEED "Gold" or "Silver". The goal of achieving a high score may be considered to be more important than achieving a good overall product (Cole, 2003). In addition, the results of all categories are converted into a score. Each category has to attain at least a "pass", however, categories have very limited or no minimum requirements and a detraction of credits for polluting components does not exist. Therefore, a project can contain very environmentally unfriendly components in a specific category, and still achieve a high final score. This checklist approach, where the meeting of individual performance requirements is pursued in the quest for a certain overall rating, detracts the designer from the more fundamental issue of ethics and professional responsibilities. More skilled design teams recognize that the interrelationship between the different strategies and systems is key to successful sustainable design (Cole, 2003).

Refurbishment. Some CBT's (e.g. BREEAM) have developed a special tool for refurbishment, in which the criteria and weightings are adapted to suit refurbishment better. Refurbishment can thus be tested by means of these tools, however, cannot be compared to new construction, because it concerns separate tools whose scores are not comparable.

Life Cycle Assessment Tools.

Life Cycle Assessment (LCA) is "a method for analysing the environmental burden of products (goods and services) from cradle to grave, including extraction of raw materials, production of materials, product parts and products, and discarding them by recycling, reuse, or final disposal" (Guinée, 2002). LCA is defined as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (International Organization for Standardization (ISO), 1997). The most advanced and most used software tools for Life Cycle Assessment of products are Simapro (Netherlands) and Gabi (Germany). Life Cycle Assessment software tools that can be used to assess buildings include: ECOSOFT (Austria), EcoCalculator (Canada), Eco-bat (Switzerland), LEGEP (Germany), GaBi-Build-IT (Germany), SBS (Germany), ELODIE (France) EQUER (France) COCON (France), ECO-QUANTUM (The Netherlands), GreenCalc+ (The Netherlands), EcoEffect (Sweden), IMPACT (UK) and BEES (USA).

The indicator called "embodied energy", lies at the basis of Life Cycle Assessment. The so called "initial" embodied energy is the sum of the energy that is consumed by all of the processes associated with the production of a building, considered as if that energy was 'embodied' in the product itself. As buildings are designed to be more and more energy efficient during the operational phase of the life cycle, the initial embodied energy becomes relatively more significant. The initial embodied energy of a building is a significant multiple of the annual operating energy consumed, ranging from around 10 for typical dwellings to over 30 for office buildings (Ciravoğlu & Taygun, 2013).

The "gross life cycle embodied energy" consists of the total embodied energy during the life cycle of a building, taking into account not only the initial embodied energy that was used in initially construct the building, but also the operational energy, the embodied energy used during maintenance and/or refurbishment and the energy used to dismantle or demolish the building and dispose of- or recycle the materials (Ciravoğlu & Taygun, 2013). With the recycling and re-use of the materials, a part of the embodied energy of those materials can be detracted from the gross life cycle embodied energy. Based on LCA, a zero energy building consists of a building which will produce enough energy during its lifetime to recover this energy debt (Storey and Baird, 1999), while a zero energy building generally only accounts for the energy debt created during the operational use of the building.

The aspect of embodied energy, although it is vital to the ideology of Life Cycle Assessment, is only part of the actual assessment methodology. Following ISO 14040, an LCA consists of four components or steps (AIA Guide to Building Life Cycle Assessment in Practice);

1. Goal and Scope Definition,
2. Inventory Analysis,
3. Impact Assessment,
4. Interpretation.

In addition to the calculation of embodied energy, which is part of the inventory analysis, environmental effects and impacts are also assessed in LCA methods. These consist of (e.g. EcoQuantum v.2.00): Environmental effects; Material use, Energy consumption, Water consumption. Environmental Impacts; Depletion of abiotic resources potential (ADP) Global warming potential (GWP), Ozone depletion potential (ODP), Photo-oxidant formation potential (POCP), Human toxicity potential (HTP), Aquatic ecotoxicity potential (AETP), Sediment ecotoxicity potential (SETP), Terrestrial ecotoxicity potential (TETP), Acidification potential (AP), Eutrophication potential (EP)(Itard & Klunder, 2007).

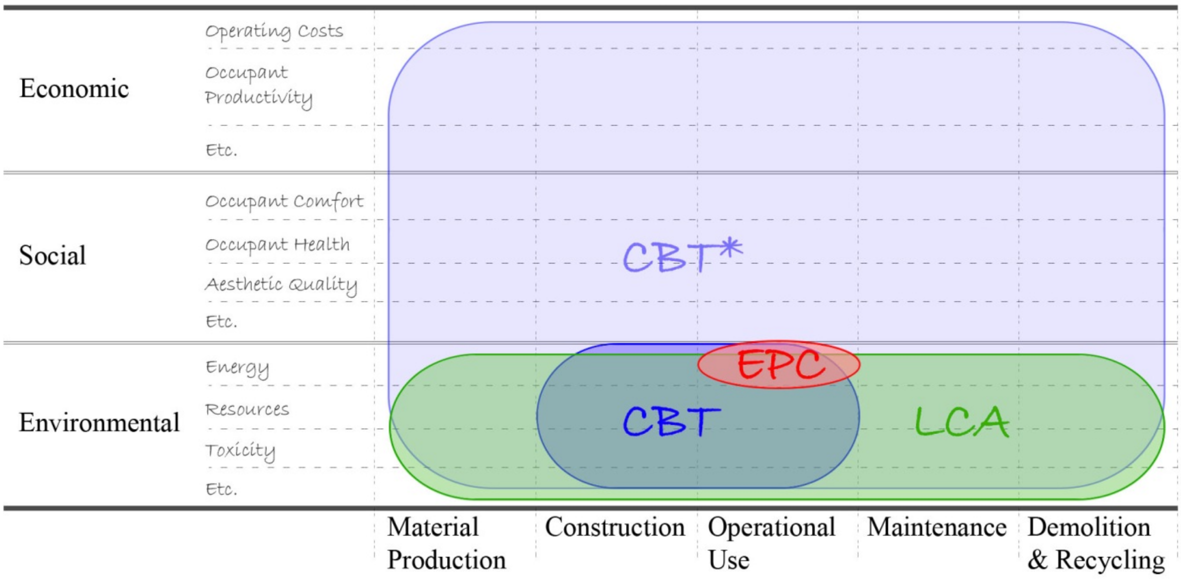
Pros & Cons. LCA is a scientific way of determining environmental impacts, based on international databases, calculation methods and ISO standards. The LCA-based methods have an in-depth coverage of environmental impacts associated with design and building materials. The latter is not unexpected because the methodology essentially builds on LCAs of products used in the building industry. Moreover, LCA-based instruments allow for estimates of the relative improvements associated with specified changes in design or the choice of building materials (Reijnders & van Roekel, 1999). LCA is based on a long-term vision, taking into account not only what is sustainable now, but also relating this to the past and the future of a product. Doing an LCA for buildings is very complex (compared to normal 'products') for four reasons; firstly buildings have a long and difficult to predict longevity, secondly a building usually undergoes many changes in form and / or function during its lifetime, thirdly a significant part of the environmental impact takes place during its use, fourthly, every building is unique and there are many different parties involved in the life cycle of a building. For these reasons, and because LCA is relatively new to the building industry (AIA Guide to Building Life Cycle Assessment in Practice), they are still less developed and less widely used than the CBT methods. Also, LCA contains no direct coverage of the indoor environment (Reijnders & van Roekel, 1999).

Refurbishment. LCA is ideal for evaluating a refurbishment process compared to other options. When taking into account the existing embodied energy already present in the existing building and the energy and materials used during demolition and construction of a new building, it is possible to compare the environmental impacts of refurbishment versus demolition and new construction through LCA.

CONCLUSION AND DISCUSSION

When the definition of sustainability, the existing legislation in the field of sustainability and the existing certificates and methods in the field of sustainability are put into relation with one another it becomes clear that these don’t match. The legislation, and the consequent Energy Performance Certificate, concentrates on energy consumption during the operational use of a building. The commonly accepted definition of sustainability, the triple bottom line, focuses on environmental, social and economic health; planet, people, profit. These three categories are also reflected in the standard definition of a “green building”, in addition, it specifically mentions the importance of taking into account the different stages of a buildings life, from construction and service life, to what happens after a buildings service life. The latter lies at the basis of Life Cycle Assessment methods: covering a much wider spectrum of environmental sustainability, taking into account different stages of the buildings life cycle and concerning a large range of environmental impact criteria in addition to energy. Social and Economic aspects, however, are not reflected in an LCA. The Criteria Based Tools do take into account economic, social and environmental sustainability aspects, although the main focus lies on the environmental sustainability impacts during the construction and operational use stages. These different areas of sustainability **are shown in Table 1**, clearly showing the extremely narrow part of sustainability that the legislation and the associated Energy Performance Certificates are focusing on. Also, the Criteria Based Tools have two separate indicated areas, one that stands for its main focus area, and one covering the wide range of rather superficial indicators covering the entire spectrum of sustainability.

Table 1. Spectrum of Sustainability in the Built Environment



The fact that legislation and regulations are concentrating on energy consumption during the operational use of a building has led to this principle being translated as “sustainable” in practice. A building is considered to be extremely sustainable when a zero energy value is achieved. The fact that in these cases other aspects of sustainability are completely ignored is problematic. Concepts such as "passive building" and "energy-neutral home" are popular, and national and international standards concentrate on attaining extremely high insulation values of the shells of buildings. That this insulation may often be environmentally polluting is completely disregarded. Also, there is for example the extensive use of solar panels to balance out the operational energy, while completely disregarding the embodied energy and environmental impact that was necessary to create the solar panels in the first place, a kind of deceptive sustainability. In relation to refurbishment, these regulations are also very problematic. Buildings that reach a certain age fall short of adequate operational energy efficiency to fill current standards, and are consequently threatened by large-scale demolition; to achieve the highest possible energy label demolition and new construction often are an easier option than refurbishment. The embodied energy present in these buildings will be discarded, the resources used in the new construction will not be accounted for, and the waste that is produced because of this is ignored. These things will not stand in the way of the newly constructed building achieving the highest energy certificate level, nor will it stand in the way of the newly constructed building being awarded sustainability prices and being promoted as “best practice”.

However, as described in the article, there are other assessment methods that try to provide a more complete assessment of sustainability. Unfortunately, they are very complex and require training and certification to be able to use them (Nguyen & Altan, 2011). As a result, they are not accessible and are often used at the end of the design stage instead of being used early in the design process while the most important decisions with regard to sustainability should be made at the beginning of the design process (Zeiler, 2011). They are therefore, and because they are completely voluntary in their application, far from standard in use.

The use of a different list of indicators in different approaches makes a definition of the term “Sustainable Construction” subjective and causes difficulties in comparing results from different tools. A case-study comparison by Zeiler (Zeiler, 2011) where eight different case studies were tested by four of the most popular assessment methods (LEED, BREEAM, Greencalc, Ecological Footprint), proved the outcomes to be completely different. A building could be considered most sustainable by one tool, and least sustainable by another. In order to overcome these constraints, both the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have worked actively in the last few years to define standard requirements for the environmental and sustainability assessments of buildings (Mateus & Bragança, 2011). Both standards ISO/TC59 and CEN/TC350 take into account economic, social and environmental sustainability and aspects regarding a products life cycle from cradle to grave, they provide general definitions and principles regarding indicators and calculation methods for assessment tools. These standards do not set the rules for how building assessment schemes may provide valuation methods, nor does it prescribe levels, classes or benchmarks of performance (Technical Committee CEN/TC 350, 2010). Since these standards are not mandatory nor completed yet (especially on the part of social and economic sustainability), they haven’t been fully integrated in the assessment tools yet.

Efforts are being made to integrate LCA methodologies in CBT tools, trying to combine the measurability of LCA’s with the wide range of sustainability aspects covered in a CBT. Environmental issues are broad and difficult to capture, combining qualitative and quantitative data, a balance between completeness of coverage and ease of use remains one of the challenges in developing an environmental building assessment tool.

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Sustainable Hotel Industry from the Perspective of the Social Environmental Management

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ABSTRACT

Sustainable projects development cannot be considered just from the perspective of passive design, sustainable construction, and energetic efficiency of the building during its life cycle. Other dimensions of systemic sustainability must be involved as a part of the real-estate management model, in order to increase its importance and establish equity and efficiency based on relationships with the economic and cultural context where each project is located. This point of view starts off by recognizing that construction is not just a contaminating, noisy and negative transformer of the physical medium activity, but it is also a promoter of positive cultural and social transformation of the community located around the project.

A social-environmental management model is presented based on this condition, which allows a hotel-oriented construction to establish cooperation and integration networks with its neighbors, starting right from the preliminary design stage, the construction stage and involving its future operation. This sustainable social management model involves, during the development of the Terra Bio-hotel project, the participation of social sciences professionals like historians, sociologists and anthropologists, whose management of the community made possible to include the hotel project, during its construction process, in the imaginary of a traditional community of Medellin, embracing a contemporary project as a new neighbor, which stimulates the life in the neighborhood and joins the community with cultural, artistic and environmental management activities. In this social-environmental management stands out the participation of the neighborhood administration board on the projection of its social model with a regional scope, through projects like: agro-ecological market, solid waste comprehensive management and historical memory recovery.

INTRODUCTION

In terms of population and economic dynamism, Medellin is the second largest economy in Colombia and holds a high visibility within the Latin-American region, due to its recent development in urban infrastructure and equipment. It has been a decade since the city was projected as a business destination by promoting and consolidating it internationally. However, its hotel infrastructure –which is expected to host a high volume of visitors and people invited to different fairs, conferences and events- does not differ significantly from a traditional model of hotel industry that makes an intensive use of renewable and non-renewable resources, such as water, energy and food – involving high environmental and social impacts during the life cycle of buildings. In this scenario, alternative experiences serving as a model –or laboratory- are pertinent and useful in order to incorporate the notion of systemic sustainability in Colombia's and Latin America's hotel industry.

Terra Biohotel is a hotel project with 41 rooms and an area of 2,666 m^2 built (about 28,697 ft2). From its design phase, it was conceived as a technical and technological innovation proposal based under the principles of "Systemic Sustainability" (El Khouli, 2011), "Territorial Social Responsibility" (in Spanish "Responsabilidad Social Territorial") (Alquimia, 2012) and "Glocalization" (Robertson, 2003). These conceptual premises aim to minimize the negative social-environmental impacts and to potentiate the positive impacts of the hotel project throughout its life cycle. In order to carry this out, sustainable strategies were implemented in Terra Biohotel during its design and construction phases, while actions to guide the project sustainability during its operation phase are planned.

SUSTAINABILITY IMPLEMENTED IN THE DESIGN PHASE

Bioclimatic passive design strategies in Terra Biohotel architectonic project are based on the analysis of the location, the environmental preexistences and the variables prioritization such as solar incidence, natural lighting, natural ventilation and noise (García, González, & Salazar, 2006), and were complemented with the method of projecting for the High Environmental Performance Architecture (AADA, for its acronym in Spanish) (Bedoya, 2011) The results of this design exercise made it possible to build a structure whose exposure to direct solar radiation is minimized (See Figure 1, letter a). The project counts on a performance of natural lighting superior to 8 hours a day and a natural ventilation system that allows guests to do a secondary use of the air conditioning system, achieving –this way- energy efficiencies superior to 50%, compared with a conventional building of the hotel industry in Medellin.

SUSTAINABILITY IMPLEMENTED IN THE CONSTRUCTION PHASE

Social-environmental resident building manager: according to the current building policy in Colombia, it is not mandatory to hire this type of professionals in private projects. However, Terra Biohotel decided to employ an environmental engineer, so he could control the environmental impact during the construction phase, as well as the social relationships between the neighborhood residents and the Project.

Construction and Demolition Debris (C&DD) comprehensive management: during the construction phase of the project, C&DD were constantly separated at source (See Figure 1, letter b), which maximized their subsequent reusing and recycling. The results obtained from these processes are: 514 m3 (about 18,152 ft3) of C&DD were reused in a road in a near construction site; 449 m3 (about 15,856 ft3) of concrete, mortar and stone material waste were recycled and concrete blocks for the hotel envelope construction were made with it; 6,900 kg (about 15,211 lb) of wood were reused as biomass; 593 kg (about 1,307 lb) of metallic waste and 188 kg (about 414 lb) of polyvinyl chloride (PVC) were recycled by specialized companies. In the course of the construction process, paper, cardboard, glass and plastic were constantly separated and given to an informal recycler who worked in the neighborhood.

Figure 1 (a) Sample of sun protection element in the building and (b) C&DD separation.

Water resources comprehensive management: Throughout the construction phase, a water recirculation system was installed in the block cutter machine and in the concrete mixer. Water losses produced during the cut were supplied with the water resulting from the concrete mixer washing, producing –as a result- a closed cycle for water reusing (See Figure 2, lettes a and b). Such strategy made it possible to reuse 34,413 l (about 9,090 US gal) of water which contained a high amount of sediment, and to prevent their discharging as well as the contamination of proximate water sources and possible obstructions in the urban rainwater harvesting systems.

Selection of materials: the materials selected for the construction phase of the project were eco-materials, coming –as much as possible- from low-polluting production processes and from recycled materials that could be recycled again at the end of their life cycle. Moreover, in order to prevent a high level of emissions to the atmosphere due to the transportation, materials were locally obtained. The most representative material in the project is the recycled concrete block which was used in the masonry of the building. This material is made up of a 38% of recycled concrete and the block supplier company has been provided with it– as a by-product of the construction phase- by Terra Biohotel. The 95,237 blocks required for the construction phase contain 268 metric tons of recycled concrete, which is equivalent to the same amount (in metric tons) of natural stone aggregates that did not have to be exploited in the quarries of the area.

During the execution of the structural concrete, Fuel Oil N. 2 was replaced by a natural oil coming from the castor oil plant and used as a non-stick and mold release agent for the concrete formworks, avoiding –this way- the generation of a dangerous waste with a high potential of water and soil polluting.

Atmospheric emissions and noise control: the measures implemented to mitigate the spread of particulate matter in air and to reduce the sound pressure levels which the residents living near the project are exposed to were: 1) Covering the fine construction materials and the excess material from excavations. 2) Moistening uncompleted surfaces as well as those ready to be swept. 3) Closing the area intended for the block cutter and concrete mixer since they were potential sources of noise. With the objective of improving the acoustic insulation of these closing areas, part of the expanded polystyrene used in other construction processes was reused. Introducing such measure for reducing air and noise pollutants contributed to the cordial relationships with the people living near the construction, who recognize that *Terra Biohotel* is a social caring company.

Construction worker training: the project construction workers were constantly trained about sustainability and safety, which contributed to create an environmental awareness and a self-protection consciousness (See Figure 2, letter c). These experiences were later replicated in other construction projects. They also implemented some of the new ideas, such as management and care of water, in their own homes.

Figure 2 (a) Double sedimentation in the process of block cutting, (b) Pumping of clarified water to be reused later in the block cutter and (c) Construction worker training.

Sustainable School-Hotel: during the construction process, the transference of experiences and knowledge was fostered. Terra Biohotel has embraced students and professors from different universities of Colombia who have been interested in going into detail about the sustainable component of the project (See Figure 3, letter a). Some of the undergraduate students are carrying out scientific initiation researches, graduation theses and professional practices about the project development. The initiative of "Sustainable School-Hotel" aims to transmit a message of systemic sustainability to the community, to the government and to the organized civil society, by means of the promotion of networking and mutual learning and citizen awareness about the clear connection between their consumption habits and life style with the environmental degradation and the magnification of the social gap separating individuals in a same community.

Development of a sustainable community: with the goal of putting into practice the systemic sustainability approach, set as one of the most important premises in the project *Terra Bio Hotel*, it was necessary that the management model went beyond the notions of passive design, energy efficiency and construction under environmental sustainability, towards the development of a sustainable community. To carry this out, *Terra Biohotel* unified efforts and works with the Communal Action Board of the neighborhood *Los Conquistadores* in the city of Medellin, whose leaders and representatives agreed with the objectives to develop sustainable management initiatives in the area of the hotel project. It is also expected that the residents take responsibility –individually and collectively- for their negative social-environmental impacts and take part in the execution of specific tasks, namely the mitigation or reversion of such impacts.

This social collective work, together with the Communal Action Board of the neighborhood *Los Conquistadores*, favored the spreading of the sustainable systemic initiatives of the project, aiming to go beyond the citizens' everyday reality to increase their social-environmental culture levels in order to obtain a healthier environment for everybody, by promoting a healthy diet, the sense of caring and belonging of public space, the neighborhood historical memory recovery, the appropriate and conscious use of water sources, and the comprehensive solid waste management by means of recycling. Next, three initiatives that run today with the Communal Action Board of the neighborhood are described:

1. Agro-ecological market: it fosters health care among the residents of the neighborhood by encouraging people to consume food products –free of pesticides and chemical fertilizers- coming from the countryside. This initiative looks forward consumers to be more aware of the environmental quality of the products they eat. And –at the same time- it is expected to provide the neighborhood with a meeting place where people can reinforce the social fabric, by fostering environmental consciousness together with culture and ludic activities. Such enterprise becomes real with the contribution of the community, private companies and the public sector (See Figure 3, letters b and c).

The agro-ecological market enabled the fact that a group of farmers from the rural area of Medellin could commercialize their products directly with consumers, raising their incomes as well as their quality of life, while the people from the neighbourhood can buy healthy products. Up to June 2014, nine monthly versions of the agro-ecological market have taken place in the neighbourhood *Los Conquistadores* with the help of *Terra Biohotel*. The market is now recognized because of its approach of systemic sustainability and other neighbourhoods in the city have replicated the idea. All of this is just an alternative that promotes the responsible consumption, solidarity and collective welfare.

Figure 3 (a) Post-graduate students from Monteria, Colombia visiting the proyect, (b) Agro-ecological market and (c) Training conference about healthy diet provided by the Mayor's office within the agro-ecological market.

2. Solid waste comprehensive management: this plan intends to strengthen the resident environmental education in order to motivate them to manage solid waste rightly, to reduce waste in sanitary landfills, to avoid health problems related to the growth of unhealthy vectors, to create formal employments, to reduce the street cleaning tax for residential complexes, and to generate a prototype experience in waste management that could be replicated in another places of the city.

To develop the solid waste management in the neighborhood, there is a team who meets weekly and that is composed by the public sector: Secretary of the Environment and Natural Resources of Medellin (*Secretaría del Medio Ambiente del Municipio de Medellín),* the private sector: *Terra Biohotel,* the academy: University Colegio Mayor de Antioquia (*Institución Universitaria Colegio Mayor de Antioquia*), and the civil society: neighborhood *Los Conquistadores* residents. The work of this team is now materialized in the proposal of a project dealing with solid waste management for the neighborhood, which will be administered by the Communal Action Board, as a representation of the inhabitants.

3. Historical memory recovery: this project aims to preserve the neighborhood's identity and historical memory by means of appealing stories about the beginning, the history and the development of the neighborhood. With the narrative and visual material collected, it is expected to organize cultural events that broadcast the recognition of the neighbors with their community. Moreover, elderly population will be invited to participate in the *Terra Biohotel* initiatives concerning education in systemic sustainability (See Figure 4, letter a). Art, culture and ludic are invited to this project as facilitator elements for this idea become established (See Figure 4, letter b).

Figure 4 (a) Resident storytelling recovering and (b) Artistic exhibit in the event "Cuando el Río Suena… Arte Lleva", ("When the river sounds…there is art in it") supported by Terra Biohotel.

SUSTAINABILITY DURING THE OPERATION PHASE

Comprehensive water resources management: *Terra Biohotel* will re-use the gray water from the building to garden irrigation and hotel toilet flushing. The project has a water purified system the of the phreatic zone, which will allow a quite important level of self-supply, under the granting of a license by the authority that regulates water resources in the city. The implementation of these measures will reduced the social environmental impact that generates water capturing, processing and distribution in Medellin's water supply network and will reduce the operating costs in an approximate proportion of 30:1.

Energy efficiency: the bioclimatic design of the building structure will minimize the use of electric energy associated to air conditioning and artificial light consumption in the hotel in a proportion of 50% of a conventional energy operation in hotels of similar type and size. The hotel is provided with high energy efficiency machines, such as LED lamps, solar collectors for heating water and an air conditioning system adapted to the geographical location and climate conditions of the city of Medellin.

Comprehensive solid waste management: in the hotel operation, recyclable waste will be gathered, ordinary waste will be compacted, and organic waste will be composted to minimize the volume of solid waste dumped in the open-air sanitary landfills of the city.

Sustainable destination-hotel: the *Terra Biohotel* model of systemic sustainability management aims to organize an environmental, gastronomic, cultural, pedagogical, and patrimonial tourist offer which set the city and the region as an interesting sustainable tourist destination.

Broadcasting and sensitization: besides the commercial and economic management of the hotel project, a constant pedagogical management will be developed and will be oriented to inform the people directly interested in the project -potential clients, employees, suppliers, residents, authorities, students and professors-, so they become sensitized about the problems that the current unsustainable model has, by promoting systemic sustainability: a socio-economic and environmental balance.

CONCLUSIONS

The main contribution of this paper is the exploration of the social dimension in the systemic sustainability incorporated to the building industry, during the phases of construction and life cycle of the building . Regarding *Terra Biohotel,* it is important to remark its interdisciplinary contributions that go beyond the role of architecture and construction and that aim to reduce the environmental impact caused by construction, to achieve a strong community social incorporation and to create shared value, even in commercial uses, such as hotel industry, whose impacts are not taken into account during the planning, design and operation of a project. This environmental and social facet of systemic sustainability shows the impact of management micropolitics wills, linking the local neighbourhood management with the private sector of construction, in order to point the hotel project towards an exercise of economic sustainability, able to exceed the relation cost-benefit, supported on the environmental and social responsibility of construction.

Experiences developed and documented in this paper highlight the contributions of Terra Biohotel in a social, economic and politic context, whos management could become a proofing experience, able to contribute with environmental, social and economic analysis elements, in comparison to the problems resulting from the impact that conventional construction has, from the perspective of territorial social responsibility, glocalization, and governance, and to provide alternative solutions that influence the Colombian and Latin American reality.

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Session 8D : Integration of renewable energy

PLEA2014: Day 3, Thursday, December 18
14:10 - 15:50, Grace - Knowledge Consortium of Gujarat

Zero Energy Solar-House Technology Aiming Greenhouse Gases Emissions Reduction by Residential Sector in Brazil

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ABSTRACT

This study aims to define a Zero Energy Solar-House and analyses its contribution to global warming mitigation by reducing Greenhouse Gases (GHG) emissions. This study identifies guidelines for a Solar-House project regarding electricity use, environmental conditioning, solar systems and equipment in order to obtain energy efficiency. Data to evaluate the Solar-House model are provided by Ekó House Project, which is a solar house prototype. The balance of GHG emissions reduction focus on electricity consumption, and to account avoided emissions this study considers solar photovoltaic (PV) generation instead of grid electricity, as well as energy efficiency measures harnessing the sun's energy on a passive way. This study goes through a comprehensive analysis of Brazilian electricity system, the use of electricity by the Residential Sector and GHG emissions associated. As a result, this study sets basic guidelines for a Zero Energy Solar-House and accounts the potential do avoid GHG emissions with this housing model. Benefits due to large-scale implementation of this model in Brazil are evaluated. To measure the impact of these solutions on a larger scale is taken as geographic boundary Southeastern Brazil – a region with high population density and need for importing energy from other regions of the country – where this study considers the adoption of energy efficiency measures and PV generation for a percentage of dwellings. Results show potential to avoid up to 0.9 Mt CO_2 emissions each month. From an interrelated analysis of solar PV generation and energy efficiency assessments, this study concludes that the solar-house taken as a reference has a significant potential to reduce GHG emissions, contributing to Brazil's sustainable development and global warming mitigation.

INTRODUCTION

The current economic development model considers the environment as an endless source of natural resources and final destination, with unlimited capacity to receive waste generated by human activity, embracing inefficiency and wasteful use of natural resources, especially energy, which is one of the essential supplies for the basic conditions of human life. Such model and the unbalanced operation and use of environment are the vectors of environmental problems.

Brazil is a developing country and as so, the tendency is that energy demand will increase along with the economy, implying the construction of new hydroelectric and thermoelectric plants, causing significant environmental, social and economic impacts. The residential sector consumes 26% of total

Brazilian electricity, and the increment of population purchasing power leads to an increase in energy consumption by this sector. This highlights the need to adopt energy efficiency measures and alternative and renewable energy sources, so that people can have access to consumer goods and improve their quality of life in an efficient way.

The Brazilian energy matrix is considered clean. In the National Interconnected System (SIN), 67% of energy comes from hydropower. Nevertheless, increasing concern with environmental and social impacts of the construction of new plants has been noticed. On the other hand, studies show the enormous potential for the exploitation of solar energy in the country, due to favorable levels of solar radiation throughout the year and photovoltaic systems for distributed generation are approaching an economic feasibility (EPE 2012). Therefore, it is argued that solar energy has demonstrated potential to contribute to supply this growing demand.

Given this scenario, this study aims to determine the contribution of a Zero Energy Solar-House (ZESH) to the sustainable development through energy efficiency and the use of solar energy, allowing the reduction of GHG emissions associated to energy consumption by residential sector in Brazil. To verify the potential of these actions on a larger scale, is taken as geographical boundaries the Southeastern Brazil, considering the replacement of a percentage of single-family houses by units (or systems) in the lines of the CSZE. Methodologically this study adopts a solar-house prototype, the "Ekó House", that verifies the ZESH. Thus, it is possible to predict the effective reduction of GHG emissions associated with energy use by Brazilian residential sector.

The Ekó House prototype was developed by Team Brazil, a partnership between São Paulo University and Federal University of Santa Catarina to participate on Solar Decathlon Europe in 2012. This prototype is adopted because it meets the requirements of a ZESH and simulation data regarding its energy and environmental performance are available.

GUIDELINES FOR A ZERO ENERGY SOLAR HOUSE

This study takes as dwelling unit reference a house that generates locally its own energy from PV modules. The ZESH also uses sun energy in architectural design for passive conditioning of indoor environment, reducing energy consumption. In this sense, geometries that result in elongated facades facing north and south orientation obtain a better use of the sun throughout the year. In summer, when the sun is more directly overhead, radiation is less intense on north oriented facades than is east and west oriented facades (Southern Hemisphere). In winter the sun is lower, and radiation is more intense in north oriented facades than in east and west oriented facades, as shown in **Figure 1**.

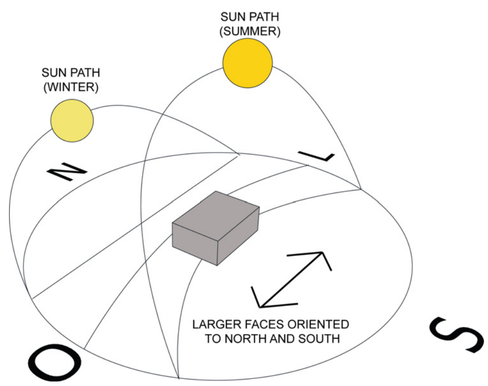

Figure 1 Solar trajectory and geometry.

The envelope elements of a CSZE have appropriate thermal performance, based on climate conditions of the implantation site, through strategies such as insulation, the use of thermal mass and/or natural ventilation. The reference prototype has high thermal insulation levels and windows properly dimensioned and positioned, ensuring natural lighting and ventilation. This results in good comfort conditions with low energy consumption by integrating passive and active strategies. Simulation models indicate a Daylight Autonomy of 60% for the Ekó House prototype (Projeto Ekó House, 2012).

In Brazil, the high investment required to improve the performance of buildings, leads people to employ low cost and low performance materials. Furthermore, there is usually no concern in adopting bioclimatic strategies to improve the thermal performance of buildings in a passive way. This implies higher energy consumption during building´s life occupancy (CANDIDO, 2010; PIRES *et al*, 2014).

In a ZESH it is essential to anticipate installation demands of solar systems, considering all components of each system on the architectural programming. The images in **Figure 2** illustrate a modular construction system and solar systems in a CSZE.

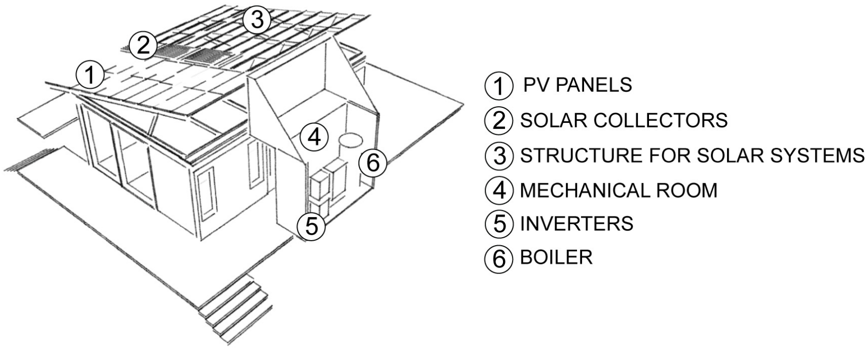

Figure 2 Solar Systems for a ZESH. (Projeto Ekó House, 2012)

The 48 monocrystalline PV panels, with an 18,5% efficiency and 11 kWp of total installed capacity generate, on average, 1.790kWh/month, enough to meet the prototype energy demand, which is around 735kWh/month, and still provide around 1.055kWh/month of clean energy to the grid (Projeto Ekó House, 2012). This positive energy balance was adopted to meet a specific purpose for which the prototype was conceived in a first moment, that is, hosting in isolated an environmentally sensitive areas in Brazil. The prototype would be connected to a local grid and could export the surplus energy to meet the demand of local facilities, like schools and healthy centers, or dwellings in these isolated locations. The graph in **Figure 3** illustrates the prototype energy balance for a typical operation year.

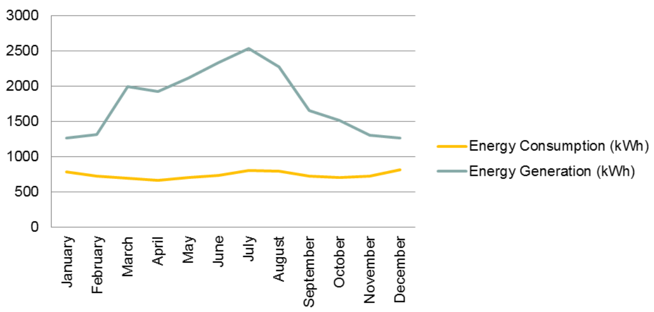

Figure 3 Energy balance for Ekó House prototype. (Projeto Ekó House, 2012)

The use of efficient appliances helps reducing energy consumption. Ekó House prototype uses National Program for Energy Conservation (PROCEL) 'level A' label. Artificial lighting, designed to complement the natural lighting, uses LED, which guarantees higher energy savings, lower maintenance and longer life. A home automation system integrated to the use of equipment and the general prototype operation contributes to a more efficient operation. This system can be programmed to guide the occupant, informing about energy generation and consumption and also control lighting and temperature, activating equipment and systems based on pre-established comfort ranges or person presence in indoor environments. **Figure 4** shows schematically the energy generation and consumption in a ZESH.

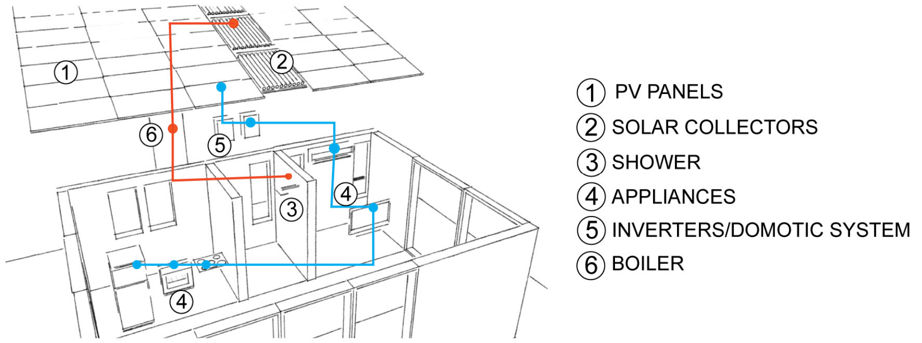

Figure 4 Energy generation and consumption in a ZESH. (From Projeto Ekó House, 2012)

ELECTRICITY SECTOR IN BRAZIL AND RESIDENTIAL SECTOR ELECTRICITY CONSUMPTION

The National Interconnected System (SIN) is a large hydrothermal system, with a strong predominance of hydroelectric plants. Only 3.4% of the country's capacity of electricity production is out of SIN, in small isolated systems located mainly in Amazon region (ONS, 2013). Hydroelectric plants correspond to 67% of energy generation, such participation enables to consider the Brazilian electricity matrix a clean matrix. Nevertheless, with the need to build new power plants to meet growing demand for electricity, more pressure comes from society and NGOs because of environmental and social impacts caused by the implementation of such new plants. Even as it is planned to extend the thermal generation in the country, including the completion of Angra III nuclear and coal-fired plants as a complement and rational diversification of usable hydropower potential naturally limited (BRASIL, 2007). It is also important to note that the losses in transmission and distribution stages reach 16.9% in SIN (BRASIL, 2012). The graph in **Figure 5** discriminates participation by source in SIN.

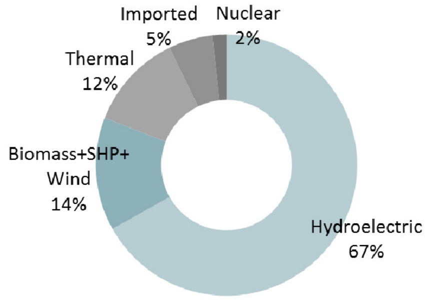

Figure 5 Participation by source in SIN. (EPE, 2012)

Another condition that highlights the need to explore other energy sources is the fact that most of the hydric resources in Southern and Southeastern are already exploited, and most of the remaining reserves are in the Amazon, away from industrial and population centers (OECD, 2001). It is important to note the potential for solar energy exploitation due to favorable annual irradiation levels in the country, ranging on average from 1.260 to 1.420kWh/m²/year (EPE, 2012). Further, the National Electrical Energy Agency (ANEEL) approved in 2012 a resolution that allows installing grid-connected PV micro-generation in dwellings.

On the other side of the equation is the electricity consumption. The residential sector accounts for 26% of total electricity consumption in the country, and it is expected that this participation will remain for the next 10 years, with an estimated increase of 48.3% by 2021. This amount considers energy efficiency measures due to use of more efficient equipment in Brazilian dwellings (BRASIL, 2012).

It is important to notice that peak demand in Brazil usually occurs by the end of the day, from 6:00 p.am. to 9:00 p.m. and is associated to use of artificial lighting, home appliances and electric shower. However, this year during the summer, new records in peak consumption were registered in Southeastern/Midwest and South SIN subsystems, as shown on **Figure 6** graphics. Such shift on peak time is associated to constant high temperature and thermal discomfort index in these regions, at the time higher insolation, which increased the use of HVAC systems (ONS, 2014).

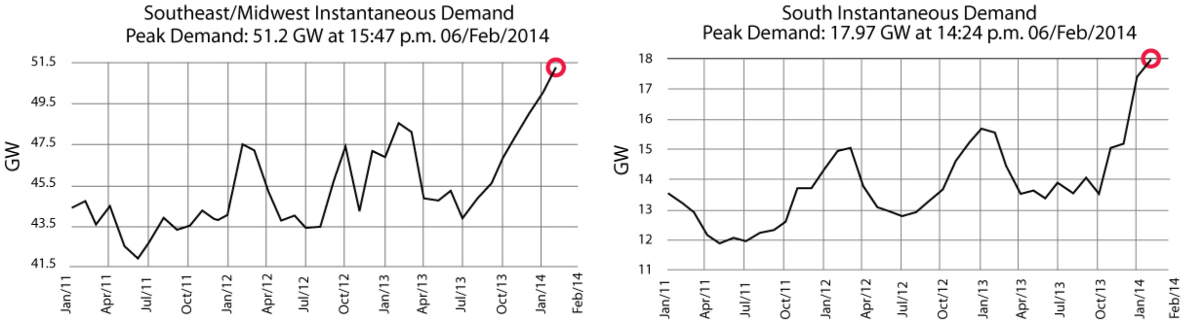

Figure 6 Instantaneous peak demand in SIN subsystems. (ONS, 2014)

Regarding the specific consumption by appliance and equipment, a research on "equipment checkout and use habits" (PROCEL, 2007) indicates the participation of different appliances in energy consumption by the Brazilian residential sector, as shows the graph on **Figure 7**. In Southeastern Brazil the average electricity consumption is around 180kWh/month for each dwelling (EPE, 2013). This indicates that there is room for increasing electricity consumption by this sector.

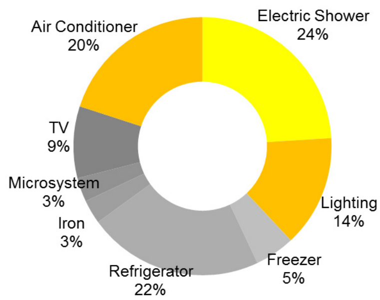

Figura 7 Participation of appliances in Brazilian dwellings. (PROCEL, 2007)

Such data regarding electricity generation in Brazil and specific consumption by the residential sector are applied to assess the benefits of a ZESH, regarding the adoption of energy efficiency measures and the PV generation by reducing energy consumption and avoiding GHG emissions.

GHG EMISSIONS BY SIN AND PV SYSTEMS

As already pointed, it is estimated that participation in electricity consumption by the residential sector will continue in the coming years, with an increase in energy consumption and, consequently, in associated GHG emissions, which must pass from 18 Mt CO2-eq in 2011 to 23 Mt CO2-eq in 2021 (BRASIL, 2012).

This study adopts the emission factor of SIN, for which the average of the last five years was 0,2926 t CO2/MWh (MTC, 2014). For the amount of greenhouse gas emissions of PV systems, are assumed values defined in the Special Report of the Intergovernmental Panel on Climate Change (IPCC), according to which the average emission factor for such systems is 0,046 t CO2/MWh (IPCC, 2012). Emissions attributed to solar photovoltaic generation are from the manufacture of photovoltaic systems and can be compensated by the manufacturer or end user.

From the combination of these data it is possible to estimate the reduction of GHG emissions that energy efficiency measures such as those adopted in ZESH and power generation by PV system can represent when applied on a larger scale.

ENERGY GENERATION AND CONSUMPTION IN ZESH

To analyze the contribution of ZESH to the sustainable development, data of Ekó House prototype are applied. Such data come from computational simulations and estimate values of generation and power consumption over a year of operation. The simulations consider developed countries comfort standards, with the presence of some appliances that, in Brazil, are not common to all population strata in the country. However, with economic development and greater purchasing power of the population, such equipment must be increasingly present in Brazilian homes, increasing the power consumption of residential sector. On the other hand, solar collectors for water heating are adopted and artificial lighting uses only LED. The graph in **Figure 8** shows the monthly consumption in Ekó House prototype.

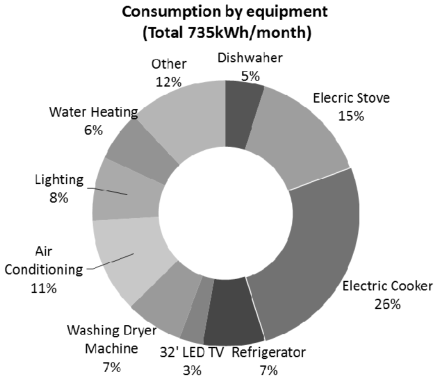

Figure 8 Consumption by equipment in Ekó House prototype**.** (Projeto Ekó House, 2012)

By comparing the simulated consumption for the prototype of 735kWh/month, with the monthly average consumption of households in developed countries such as the United States, which consumes on average 958kWh/month (EIA, 2011) per dwelling, is possible to realize that even keeping comfort levels of these countries, the prototype reaches more efficiency in electricity consumption.

To estimate the reduction in energy consumption, this study considers the adoption of solar collectors for water heating in Brazil. It is assumed that 70% of the annual demand for hot water is provided by solar collectors. Thus, the reduction in power consumption obtained is approximately 17%. Assuming that an appropriate use of the sun for daylighting and passive conditioning associated with the use of LED system and passive thermal conditioning strategies, contribute to energy efficiency with a 30% saving in consumption by air conditioning and artificial lighting systems. Thus, another 10% of total consumption would be avoided, as shown in **Figure 9**.

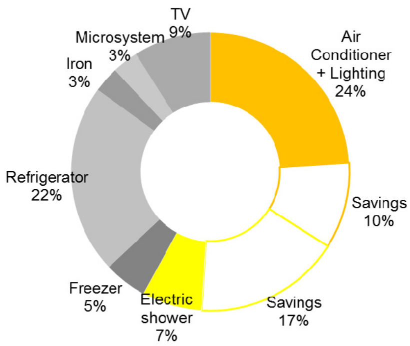

Figure 9 Energy savings for harnessing solar energy.

ZESH CONTRIBUTION TO REDUCE ELECTRICITY CONSUMPTION AND AVOID GHG EMISSIONS

To demonstrate the contribution potential of harnessing solar energy in architecture, it is taken as geographical boundaries the Southeastern Brazil, which has about 20 million households, of which approximately 80% (or 16 million) are single houses (IBGE, 2010). To account the contribution of using solar PV, it is considered that 50% (8 million) of single-family houses would adopt PV micro-generation system, similar to Ekó House, but a lower cost system to be economically viable. With PV generation, avoided emissions could reach 0.2926 kg of CO_2 for each 1.0 kWh generated. Assuming a PV system with 24 polycrystalline modules, with a 13.5% efficiency and a 3.24 kWp installed capacity, the generating would be on average 387 kWh, considering the data for São Paulo, according to RETScreen® 4 software simulation. Thus, avoided GHG emissions in SIN would be around 113 kg of CO_2/month per household, or 0.9 Mt CO_2/month considering the adoption of this PV system in 50% of single houses in the Southeastern, totaling 10.8 Mt CO_2 per year.

According to a financial analysis, simulated also on RETScreen® 4, such system would have a price around 0.35 R$/kWh, without considering incentives, which is close to the average electricity tariff in the country of 0.32 R$/kWh (ANEEL, 2014). It is also important to notice that some studies already point to an economic viability of PV systems for distributed generation in Brazil (EPE, 2012).

Taking into account the average dwellings consumption in the Southeastern, 180 kWh/month, and the projected increase in consumption of the residential sector in the ten-year horizon, the average consumption is expected to reach 270 kWh/month in the coming years. With the values assumed for energy savings through solar energy use, this consumption could be reduced by 27%, resulting in a consumption of 197 kWh/month. Such measures would contribute to stabilize consumption on a decennial horizon, even improving comfort conditions in dwellings. Thus, on average, 190 kWh/month would be delivered to the grid by each household with the PV micro-generation system, or 1520 GWh by installing micro-generation in 50% of single houses in the Southeastern, avoiding up to 0.44 Mt CO_2 of emissions per month in SIN. Still, not considering the PV generation, and considering the harness of the sun, as described above, could save 27% on energy consumption, and this would represent a reduction of about 73 kWh/month per household, or 584 GWh for 8 million dwellings, avoiding 0.17 Mt of GHG emissions.

The graph in **Figure 10** illustrates the emissions avoided by PV micro-generation in single house units and the adoption of energy efficiency measures focused on harnessing solar energy, through projections to the Southeastern Brazil. The added value comes when the manufacturer is responsible for offsetting GHG emissions from the manufacturing of PV systems. In this case, the SIN emissions factor is adopted to account GHG emissions avoided. But when the consumer assumes such compensation, the emission factor applied is the one for SIN discounting the PV systems emission factor.

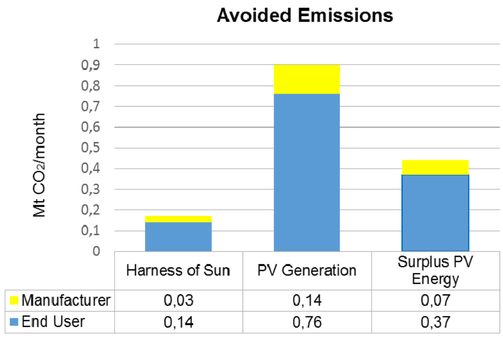

Figure 10 Potential to avoid emissions in the Southeastern Brazil through ZESH.

The study considered that the increase in consumption by the residential sector will be made according to PDE 2021 predictions. Nevertheless, this projection was made taking into account a consumption which also expresses a pent up demand for electricity in the country. With a PV with an installed capacity such as the one adopted for this study, it would be possible to reach better comfort conditions, supplying this demand with a clean and renewable source, without additional GHG emissions.

The PV generation in locations where single houses are a predominant typology can contribute to meet the demand on the network at times when other sectors require more energy than residential, like the commercial sector during daytime. The records on peak consumption during summertime point that electricity demand in SIN is increasing during daytime. This highlights that PV systems adopted on a large scale would contribute to supply electricity demand in SIN and avoid GHG emissions, by exporting energy clean energy to the grid. The use of solar collectors, LED system and the adoption of passive conditioning strategies contribute to reduce the demand for electricity at regular peak consumption time in the end of the day, when electricity demand increases in dwellings due to the use of artificial lighting, thermal conditioning systems and, specially, the electric shower.

CONCLUSION

This study demonstrates that a ZESH can make a decisive contribution to sustainable development. The combination of solar systems and energy efficiency measures demonstrates high potential to contribute in meeting the demand for electricity in the SIN through PV generation, and it also contributes to reduce demand at electricity consumption peak time.

From the projections made in this study, it is possible to conclude that energy efficiency measures help to avoid GHG emissions, mainly in the case of ZESH. The expected increase in demand for electricity by residential sector allows us to observe the relevance of such measures, in order to improve population's comfort and welfare without necessarily increase electricity consumption. However, the PV generation demonstrated an even greater contribution on avoiding GHG emissions, especially when there is surplus electricity generation that can be exported to the grid.

In short, the ZESH demonstrates potential to contribute to sustainable development of the country and use of solar energy proves to be essential inasmuch a long-term reliability on non-renewable sources can be considered unsustainable economically, socially and environmentally.

ACKNOWLEDGMENTS

To institutions that facilitated the development and implementation of the Ekó House prototype: Eletrobrás; IEE/USP; VRERI/USP, FUPAM, LabEEE/UFSC; and to the Brazilian team for Solar Decathlon Europe 2012.

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Development of Multivalent PV-Thermal Collectors for Cooling, Heating and Generation of Electricity

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ABSTRACT

Growth of cities and rising occupant comfort expectations has led to an increasing cooling demand of buildings. The use of solar energy for the production of electricity with photovoltaic modules and hot water with solar collectors is a common application. Operating the PV-T collectors at night is the possibility given to cover the cooling demand with a renewable energy source; radiative cooling. This paper focuses on the potential analysis of PV-T collectors for heating, cooling and electricity production for 6 different climate conditions. First the state of the art, four different PV-T technologies and two examples for building integration are presented. This new prototypes of PV-T collectors with different joining methodologies between the absorber and the PV module have been developed and tested at an outdoor test stand under dynamic conditions. Measurements of these four new collector types are shown and compared with a TRNSYS PV-T collector model. Finally a potential analysis for heating, cooling and electricity production for one of the developed PV-T collector was carried out under different climatic conditions. The simulation results showed that this PV-T collector has the highest cooling potential in cold and moderate climate zones where cooling is needed only temporarily. In hot and humid climates where cooling is needed over the whole year, the cooling potential of the PV-T collector for radiative cooling is less. The increase of electricity production by cooling the PV cells varies between 0,1 and 5,8 %, depending on the inlet temperature and the weather conditions.

INTRODUCTION

Hybrid PV-T (photovoltaic/thermal) collectors usually are used for heating and electricity generation. The combination of both technologies can save valuable building surface space (e.g. roof, facade) for solar installation because of the twofold use, while meeting all the energy demands of a consumer. Moreover, this technology enables retaining the efficiency of PV modules, due to the cooling effect of the thermal fluid on the PV cells, which prevents their overheating degradation. Recently, the possibility of cooling applications of PV-T collectors are being investigated where radiative cooling is employed based on long-wave radiation losses from the roof surface (for example) towards the sky driven by surface temperature difference. On a clear night, cooling capacities of 50-120 W/m² can be reached (Cremers et al., 2010 and Beck & Büttner, 2006). New PV-T-collectors have been developed and installed in the building “home^{+}” for the international competition Solar Decathlon Europe 2010 in Madrid, Spain, see section 3. The authors are currently improving this system within two research projects. The goals of the study are is to examine different technical solutions to build such PV-T collectors, to optimize and measure the thermal and electrical performances and to show possibilities for building integration with regard to architectural requirements.

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1. PV-T TECHNOLOGIES AND STATE OF THE ART

A PV-T collector is a combination of a thermal absorber and a PV module that can be joined together in different ways. In this section the joining technologies are presented, along with an overview of the classification, historical background, and current market for PV collectors.

1.1. Classification of PV-T collectors

According to the IEA SHC Task 35, PV-T systems can be mainly classified into flat-plate air collectors, flat-plate liquid collectors, concentrating PV-T collectors and ventilated facade integrated PV-modules (Hansen and Sorensen, 2006). PV-T air collectors usually generate electricity that is used only to drive the ventilator and not for feed–in to the net; in this case, solar cells occupy only a small part of the collector aperture. Within this paper only water-based uncovered flat-plate collectors will be investigated and presented. Water-based flat plate collectors can be divided into covered and uncovered collectors (Figure 1). The difference between uncovered and covered PV-T collectors is that the latter are comprised of a top cover with an air gap to the absorber to reduce the long wave radiative heat transfer and convection losses.

Uncovered PV-T collectors usually have a glass or foil protection that belongs to the PV module. The most promising application for this type of collector is radiative cooling during the night because of higher radiative heat transfer due to the absence of a top cover. Covered collectors are more suitable for domestic hot water production and heating since higher fluid temperatures can be reached. However, higher temperatures within the module decrease the electrical efficiency of the PV cells - the cell efficiency decreases up to 0,5% per 1K temperature rise (Weller et al., 2009). To avoid this decrease in cell efficiency, the module has to be cooled by a fluid, which means that the system needs a consumer load to discharge the heat, see section 4.3.

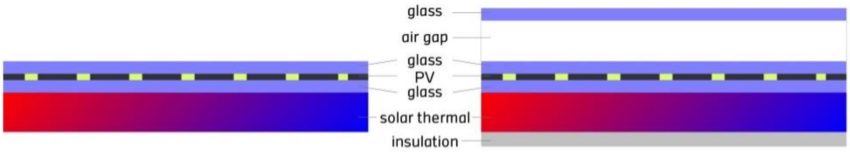

Figure 1: PV-T flat-plate liquid based collector uncovered und covered (PV on absorber area)

1.2 Historical Background

First investigations on PV-T collectors started after the oil embargo 1973/74. The focus was basically to decrease the consumption of fossil fuels and as most applications require both electricity and heating, thermal and electrical parts were combined.

Consequently, there was a need for further research in order to optimize the combination of both technologies. H.A. Zondag summarized in 2008 the historical development of PV-T collectors. The first works on PV-T liquid collectors were done by Martin Wolf in 1976 (Wolf, 1976, Zondag, 2008 and Hendrie, 1982). At the beginning, most of the research was done in the USA (and some in Japan), but in 1979 Karl also published his studies on the development of a PV-T collector in Germany (Karl, 1979 and Zondag, 2008).

Meanwhile, investigations were made to use radiative cooling towards the night sky to cool down water and also air or to discharge thermal mass on the roof (Erell, 2007). One of the first water-based radiative cooling systems was investigated by Juchau (1981). He used a regular solar thermal system for heating purposes to cool down water of a thermal storage tank during the night by circulating it through a standard flat plate collector. During the day, this water was used to cool a building through a radiant floor. In further investigations in Israel, the top-cover of a standard flat-plate collector was removed to increase the cooling power (Erell & Etzion, 1992).

The application of PV-T collectors for night radiative cooling has not yet been thoroughly researched, to the knowledge of the authors. PV-T collectors are becoming better known for cooling applications through the international competition series of “Solar Decathlons”. Various building concepts with PV-T collectors for cooling purposes, such as the home+ building from the University of Applied Sciences of Stuttgart (Eicker & Dalibard, 2011), have been constructed.

Among the obstacles that constrain the promotion of PV-T collectors on the market is the absence of a corresponding standard for this combined technology. Solar Keymark provides a certification method for uncovered PV-T collectors based on existing standards. Within this certification the PV and Solar Thermal part are tested separately; the electrical performance of the PV part according to IEC 61215 or IEC 61646 and IEC 61730 and the thermal performance according to EN 12975-1 and EN 9806. During the thermal performance test, whether the PV module is operated under MPP, OC or SC condition must be indicated, since the efficiency of the thermal performance is influenced by the electrical part. In contrast, covered PV-T collectors are potentially not covered by the above mentioned standards since they are able to reach much higher stagnation temperatures and therefore potentially will not pass the PV standards (Fritzsche, 2013). In order unify standards for the PV-T collector, the research project “PVT-Norm” (Standardization of PV-T collectors) is being carried out (Bine, 2013).

1.3 PV-T collectors available on the market

Currently, approximately 27 manufacturers are known to produce uncovered PV-T collectors with or without thermal insulation and different technical solutions. Some manufactures produce also only a thermal part of a collector that can be mounted on the back of a PV module as a retrofit. The PV module can be therefore exchanged when needed. The producers of covered PV-T collectors are not so numerous; only 5 manufactures could be identified. PV cells in a covered collector can be attached either on the absorber or on the inner side of the covering. A PV-T collector with vacuum tubes is currently being developed by a company in England, but it has not yet been commercialized.

1.4 Prototypes within the Project

Within this project, different possible combinations of materials are investigated. The aim is to develop a collector that has very good performances and is cost-effective. For this purpose, different collector variants have been built and mounted on an outdoor test stand to characterize their performances in order to evaluate the best material combination and bonding technique, and to compare the results with commercially available products.

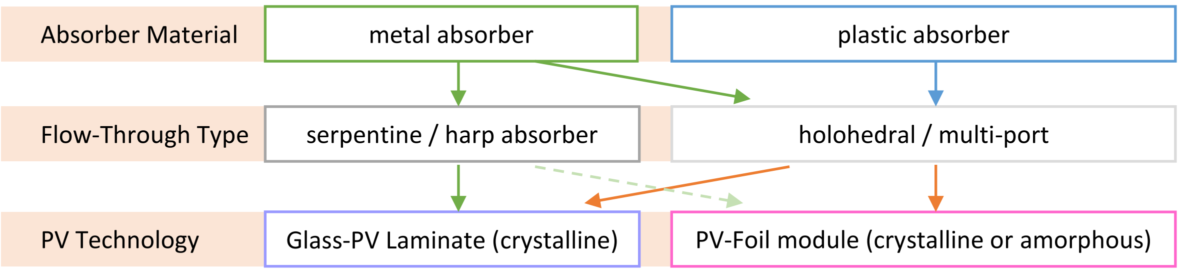

Figure 2 Different material combinations investigated

There are many possibilities of PV and absorber combinations including laminated or flexible modules with crystalline or thin film technology, both in combination with a normal deflector plate and pipe installation or holohedral flow through plastic or metal absorber, see Figure 2. The constructive aspects of PV-T collectors that have an impact on the thermal performance are mainly the thermal bond between the PV module and the thermal absorber (e.g. lamination, pressing and gluing) and the thermal resistance of the PV module itself, both of which are dependent upon the design and the manufacturing possibilities. One of the most critical properties is the thermal expansion coefficient of the PV module and thermal absorber. Consequently, the connection has to be flexible enough to balance the forthcoming dilatation of the chosen materials in addition to a small thermal resistance. Besides the thermal performance, there are other important aspects such as costs, durability and recyclability that should be considered with a new collector design.

In this paper, the following PV-T prototypes are presented (Figure 3):

Type 1 uses a polypropylene holohedral absorber fixed in the frame on the back side of a glass-PVB laminated PV module. The PV and the absorber are only pressed together.

Type 2 features the same construction as Type 1, with the difference that the polypropylene absorber is fixed with an air gap to the PV module. This simulates the building integration on a sloped roof when thermal and PV components are mounted separately

Type 3 is a laminated glass-PV-absorber module with a serpentine copper absorber. The copper tubes and the aluminum absorber are bonded to the PV module back side with heat conductive silicon glue.

Type 4 is a polypropylene holohedral absorber pressed against a laminated glass-PV-glass module with aluminum U-profile in diagonal, providing more contact zones.

Type 5 is almost the same as the Type 3, the only difference is the PV module. In this case, a laminated glass-PV-glass is used. This increases the thermal resistance between the PV module and the absorber.

In section 4, the measurements results of collector type 1-4 are presented.

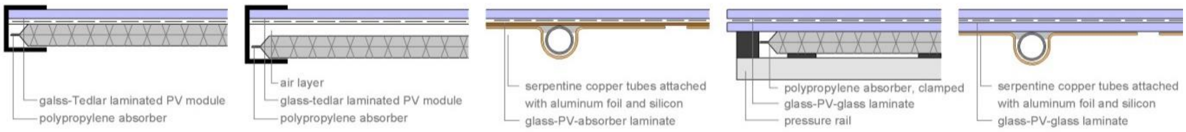

Figure 3 PV-T Prototypes 1, 2, 3, 4 (Ecolar) and 5 (home+)

3. BUILDING INTEGRATION

The type of integration of PV-T modules depends on the application and on the surrounding neighbors. One building integration requirement for a high thermal efficiency for cooling purposes is a good view angle to the sky (180°), which indicates the absorber area is as horizontal as possible. Moreover a higher building next to the PV-T area causes a reduction of the view angle, which results in a smaller radiative heat transfer rate. For cooling applications, the heat losses of the PV-T collector have to be maximized. Therefore an uncovered, uninsulated and well ventilated PV-T module is the most pertinent design. For heating purposes and electricity generation, the PV-T collector performs better if it is inclined to a certain angle, depending on the latitude of the location. However the higher the inclination is, the lower the night time radiative cooling performances are.

Consequently, a compromise must be found between cooling and heating applications. For example, cooling of the PV cell improves electrical performances, which may thereby allow for some deviation from the optimal inclination / sun orientation angles.

Figure 4 (a) Ecolar, 40m² PV-T and (b) home$^+$ (with 100m² PV thereof 36m² PV-T) and (c) detailed section of the roof of home+

Uncovered PV-T prototypes were installed on the roof in two buildings; the Ecolar building (Figure 4a) and home$^+$ building (Figure 4b), collector type 4 and type 5, respectively. In home$^+$, the PV-T modules are mainly used for cooling purposes (Cremers et al., 2010), while in Ecolar they are also used for warm water preparation. Despite the different collector designs, the collectors are both integrated on the flat roof. The PV-T collector area in home+ are totally horizontal with black monocrystalline cells and a white back sheet (module size 2,60x1,20m). In the Ecolar, the PV-T collectors are slightly sloped with black monocrystalline PV cells but with a black back sheet (1,03x4,28m). Here the PV-T area is also the water-drainage layer and a post-and-beam construction was chosen (HTWG, 2012). In home$^+$, the rain water from the PV-T surface flows between the gaps of the PV-T modules to the waterproofing layer underneath, where the water is diverted from the inclined plane as depicted in Figure 4c. According to the building simulation of home$^+$ presented by Eicker and Dalibard (2011), 43% of the cooling loads can be covered by the radiative cooling system in combination with a 1.200 liter heat sink tank for the location of Madrid.

Depending on the constructive integration level (e.g. addition, substitution, integration) (Weller et al., 2009), market available PV-T Modules are suitable for all possible building integration methods, such as in-roof mounting on pitched roofs.

4. TEST STAND RESULTS AND POTENTIAL ANALYSIS FOR SIX DIFFERENT CLIMATE LOCATIONS

As described above, PV-T collectors can be used to produce solar hot water and chilled water. At the University of Applied Science in Stuttgart (Germany) an outdoor test stand for the performance analysis of PV-T collectors was set up. The measuring process for the characterization of the PV-T collectors is based on the quasi-dynamic test method for uncovered thermal collectors of the new EN ISO 9806:2014. All important boundary conditions like wind, temperature, global radiation and longwave radiation were continuously measured and recorded. The collector field inclination at the test stand can vary between 0° and 90°, considering this roof and facade systems can be tested closely to their application. The presented measurements in the next section were carried out with an inclination of zero degrees and a collector inlet temperature near the ambient temperature.

4.1 Experimental measurements and evaluation of the results

In order to analyze the performance of the different collectors, collector types 1 to 4 have been tested simultaneously under dynamic conditions. Figure 5 shows the measured global radiation, ambient, inlet and sky temperature during the test period. The corresponding thermal power output for two days in May is presented in Figure 6.

The analysis of the measurements shows that collector type 3 performs best at day-time where the fluid is heated up and collector type 1 performs best at night-time where radiative cooling is dominant. Collector type 2 has the lowest power output at day- and at night-time, which could be explained by the high thermal resistance between the PV and solar thermal absorber caused by the air layer between the PV module and the solar thermal absorber. The thermal efficiency varies between 25 (for collector 2) and 48 percent (for collector 3). The efficiencies are low compared to standard covered flat plate collectors, which can reach efficiencies up to 80 percent during day-time. However, as before mentioned an additional glazing is counterproductive for radiative cooling application.

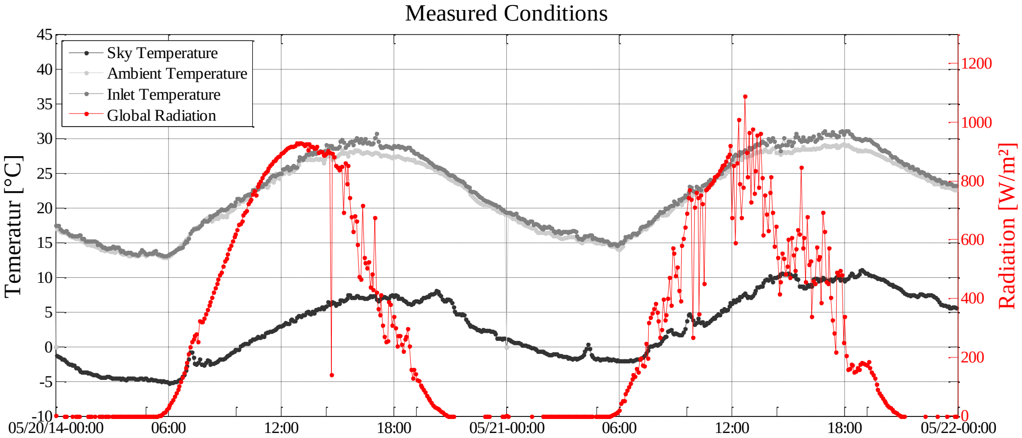

Figure 5 Measured thermal weather conditions (Stuttgart / Germany 20.05.2014 – 21.05.2014)

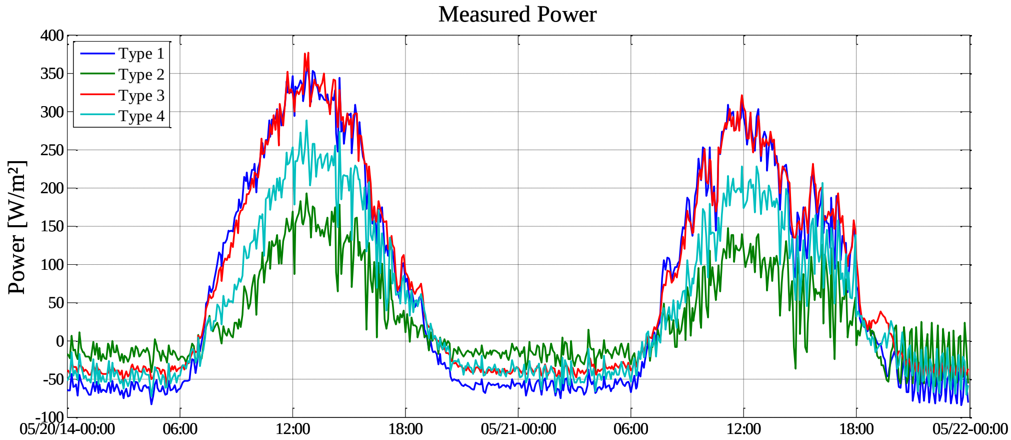

Figure 6 Measured thermal power of the collector types 1 to 4 (20.05.2014 – 21.05.2014), with an test stand inclination of 0 degrees

4.2 Climatic information for six different climate zones for the heating and cooling potential analysis

Weather data at the specific locations should be analysed in order to draw conclusions about the energy production of PV-T collectors without considering a whole building as a consumer. A common method for the calculation of heating and cooling periods from weather data files is the calculation of heating and cooling degree days (HDD and CDD). The degree-day method can be used to define the time period when cooling demand in a building is needed. The calculation is typically based on daily mean ambient temperatures. However, air conditioning systems are often turned on and off during unoccupied periods, therefore cooling degree hours or cooling degree periods better present the cooling demand. For the calculation of the CDD was obtained from the ASHRAE standard (ASHRAE. 2009) (Equation 1). The weather data for the locations was taken from Meteonorm Software (www.meteonorm.com) and represent long time mean values of the climatic conditions.

$$CDD = m_k \sum_{k=1}^{365} (T_{e,k} - T_{tc}) \qquad (1) \qquad m_k = \begin{matrix} 0 & if\ T_{e,k} < T_{tc} \\ 1 & if\ T_{e,k} \geq T_{tc} \end{matrix}$$

Where $\boldsymbol{T_{e,k}}$ is the mean external temperature at the k period of the year, $\boldsymbol{T_{tc}}$ is the threshold temperature for cooling (here 22°C). Table 1 shows the calculated cooling season, the *CDD*, the mean and standard deviation of the ambient and sky temperature for daily occupation periods from 11am- 7pm for six different climate zones as defined by Hausladen, Lied and Saldanha (2011).

Table 1. Calculated cooling season for daily occupation periods from 11 am – 7 pm

Location	Cooling season	CDD [Kd]	Mean ambient temperature and standard deviation	Mean sky temperature and standard deviation
Moscow (cold climate)	20 May – 04 Sept.	102	17,9 / 4,5	10,2 / 7,1
Stuttgart (moderate climate)	11 Apr. – 04 Sept.	155	16,3 / 5,9	7,9 / 8,4
Shanghai (subtropical)	07 Apr. – 22 Oct.	997	24,2 / 5,1	18,5 / 7,5
Chennai (tropical)	01 Jan. – 31 Dec.	3803	29,1 / 3,8	23,1 / 4,6
Dubai (coastal desert)	01 Jan. – 31 Dec.	3617	28,4 / 6,6	18,3 / 8,0
Riyadh (continental desert)	01 Jan. – 31 Dec.	3843	27,3 / 9,4	8,3 / 10,2

4.3 Simulation model verification and potential analysis of one PV-T collector with different inlet temperatures

This section deals with the quality of the simulation model employed and the potential analysis for heating, cooling and electricity production of collector type 3. The decision to use collector type 3 for the simulation study was based on the available data for this PV module and its better aesthetic for building integration (see Figure 4b). Type 203 of TRNSYS, which was developed at the Institute for Solar Energy Research Hameln (ISFH) / Germany (Stegmann, M. & Bertram, E., 2011 and Bertram, E. & Stegmann, M., 2011), was used to simulate an uncovered photovoltaic-thermal collector not only for heat and electricity production but also for radiative cooling application. Equation 2 shows the energy balance for the fluid implemented in Type 203 of TRNSYS. The electrical part is modelled according to EN 60904 and the thermal part according to EN 12975.

$$c_{eff}\frac{d\vartheta_m}{dt} = \dot{q}_N - E_n{}^{*}\eta_0(1 - b_u u) + (b_1 + b_2 u)(\vartheta_m - \vartheta_i) \qquad (2)$$

Where $\boldsymbol{c_{eff}}$ (kJ/m^2 K) is the effective collector heat capacity, $\boldsymbol{\vartheta_m}$ is the mean fluid temperature and $\boldsymbol{\vartheta_i}$ the ambient temperature, $\boldsymbol{E_n}^*$ (W/m^2) is the incident angle-corrected irradiance, $\boldsymbol{\eta_0}$ is the conversion factor, $\boldsymbol{u}$ (m/s) is the wind velocity, $\boldsymbol{b_u}$ (s/m) is the wind dependence factor for η_0, $\boldsymbol{b_1}$ (W/m^2 K) is the heat loss coefficient, $\boldsymbol{b_2}$ (J/m^3 K) is the wind dependence factor for $\boldsymbol{b_1}$, $\boldsymbol{\dot{q}_N}$ (W/m^2) is the specific thermal collector output power. The parameters for Type 203 were calculated from the measured data shown in the previous section (Figure 5 and 6) and validated against a third day. The identification of the parameters was done by adjusting the coefficients in Equation 2 that best reproduce the measurements. Figure 7 shows the measured and simulated return temperature and power output for the collector type 3.

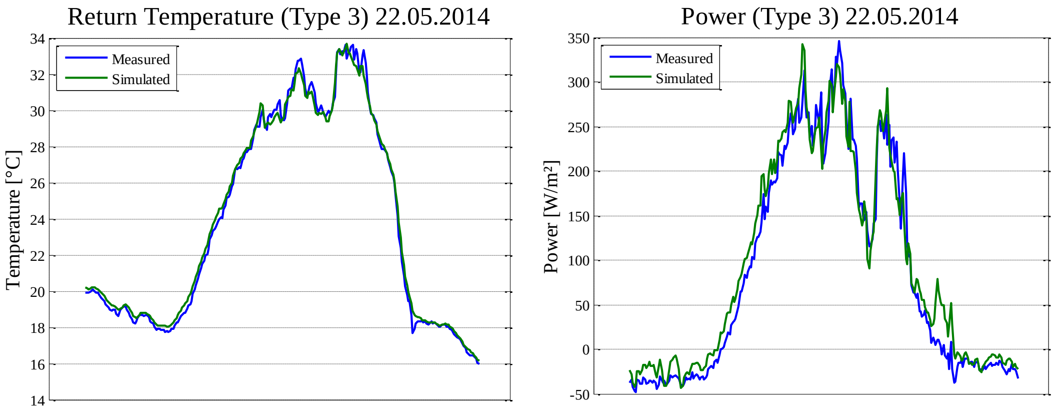

Figure 7 Comparison between measurement and simulation for temperature (l) and power (r)

For radiative cooling applications the view factor toward the night sky of the collector is very important. In this study the angle of the collector was fixed to 0° (full view to the sky), the mass flow was set to 40 kg/(m²h) and the inlet temperature was set to the collector to 25, 35 and 45°C. These inlet temperatures were chosen because they represent typical operating temperatures for systems like cooling ceilings and heat pumps.

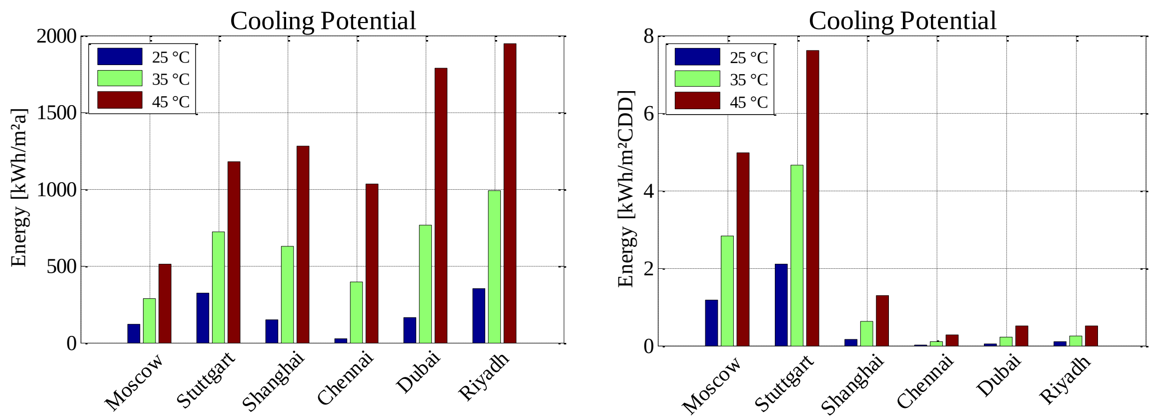

Figure 8 Simulated absolute cooling potential for the cooling season (left), cooling potential per CDD (right) for the collector Type 3

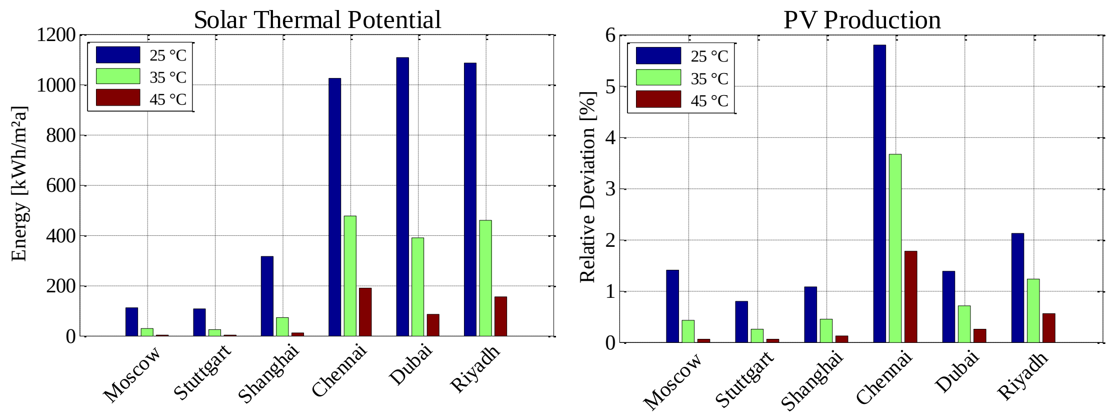

Figure 9 Solar thermal potential (left) and relative deviation for the PV production (right) for the collector Type 3

Figure 8 presents the simulation results of the cooling potential and Figure 9 the solar thermal potential and relative deviation for the PV production depending on the location and the inlet temperature. The results show a strong increase of the cooling potential with the rise of the inlet temperature. This is caused by the increase of the convective and radiative heat losses to the ambient and sky, respectively. The highest absolute cooling potential was calculated for Riyadh and the lowest for Moscow with an inlet temperature of 45°C. However, the highest cooling potential per cooling day could be found for Stuttgart and Moscow. The highest solar thermal potential is in Dubai and the lowest in Moscow, with an inlet temperature of 25°C. The highest increase in PV (electricity) production with 5,8 % was found for Chennai and the lowest with 0,1 % for Stuttgart.

4.4 Discussion of results

The cooling potential per *CDD* values presented in this simulation study particularly show high values for cold (Moscow) and moderate climate zones (Stuttgart). However, the highest absolute values can be reached in continental desert zones (Riyadh). Although the cooling season in Chennai is of the same length as in Riyadh, the absolute cooling potential is lower. This could be explained by the lower ambient and sky temperatures of Riyadh compared to Chennai, as presented in Table 1. The new prototypes presented in this paper are uncovered on the top side and uninsulated on the backside. A combination of PV-T collectors with heat pump systems could provide a higher temperature inlet temperature level to the collectors. For the design of a system that includes PV-T collectors, all three aspects, PV production, solar thermal and cooling potential, need to be considered simultaneously. However, the use of PV-T collectors in a system needs to be studied in more detail, especially the integration and the dimensioning of the system. For Chennai, Dubai and Riyadh where heating is not necessary, further research might be directed to find suitable applications for the gained energy during day-time.

5. CONCLUSION

First results show a good match between the simulations and measurements for the analyzed collector. Results prove the potential of the described PV-T collector approach to provide thermal, electrical and cooling applications, which is different from the common application of current or historical use of PV-T products on the market today. Large differences exist in the usage potential in different climatic zones as it has been described and reflected in the PV-T collector design with regard to its technical detailing and its costs, which are highly dependent on the materials, components and manufacturing technology. It is expected that a low-cost approach focusing on an optimum performance on the cooling side has the highest applicability in the areas with the highest overall performance. Another issue will be the integration of these PV-T collectors in buildings with regard to an appropriate supply system (e.g. cooling and heating incl. storage, DHW, electricity) with robust control systems and architectural design requirements.

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Parametric Analysis Method for Urban Energy Transformation Projects

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ABSTR ACT

In tandem with industrialization, migration from rural to urban has caused unstructured and unplanned cities. On the other hand the needs of people in the cities have begun to change according to overpopulation, new technologies and life styles. This change results in growing energy demand at the cities and the governmental authorities and municipal services has to respond it. Urban transformation projects are given as a solution for struggling with these problems and reshaping the cities. Energy, one of the main topic on the urban transformation projects, contains the efficient resource and energy management, minimization of the energy consumption as far as possible and capacity enhancement for renewable energy sources. While developing urban transformation projects, the optimal and effective solutions should be investigated for the project area having regard to applicability, environmental impact, and economical feasibility. In this research, the energy demand profiles of generic residential urban blocks for two city locations in Germany and Turkey are simulated using EnergyPlus to identify the site density and physical properties effect moreover the significance of site design on future renewable energy integration opportunities. The research shows that 10-20% energy demand can be saved by an energy aware site planning and the urban transformation projects also have a big potential to supply more than 30% of the energy used with renewable energy sources.

INTRODUCTION

At the end of the 19th century with industrialization, many people began to live in the cities which are the centre for trade, industry and transport. Migration from rural to urban area has gained accerleration with education and business opportunity in middle of 20th century. Today half of the world population lives in cities and it is predicted to increase to more than %65 by 2050 [UnitedNations, 2008]. Nowadays, cities are the overpopulated sharing place of all networks such as transportation, services, finance, social spaces, cultural links, etc. Therefore management of all networks in cities is concerned with configuring, efficiently and equally supplying of the resources to the citizens and ensuring the continuity of the cycles for sustainability.

Especially in Europe, cities have been developed over hundreds years ago. Zonning, structure and network systems were consisted with industrialization but nowadays the European cities are transformed to management centers with head quarters of many firms so cities have to be globalized with sharing network and they need additions or refurbishment for information age [Thorns, 2002].Another point worth mentioning is that new poor citizens (not in Western Europe but rest of the World) who came to city with hope of job placement, solve their residence problem by ownself and living area capacity of the

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city has been increased many times without planning or structuring the new development areas. It is estimated that by the year 2035 half of the world poor population will live in this unplanned areas [Horwood, 2007]. It means that this population will begin to live in unstandardized building blocks with lack of infrastructure and with insufficient supply mechanism. It is big challenge to struggle with this problem for city managers.

Besides that, life style in cities and the technology has metamorphosed the demand of people. Industrial production and modern-day consumers with increasing wealth require more energy for daily needs. Basically all international and national governmental or local authorities deal with this energy management problem. On the other hand authorities have an important role on reducing green gas emissions and climate change mitigation. There is a big opportunity to make a cost effective saving in the energy demand of city building stock and provide the sustainable environment development for cities.At this juncture, sustainable urban development becomes even more important for future of urban life. Sustainable development first appeared in the literature during the 1970s and 1980s and early 1990s the issue of sustainable development gained momentum. After the United Nations' Rio Conference's Agenda 21, sustainable development is preferential as policy for every urban authority (Beatley and Manning, 1997). Many projects and programs are going on for sustainable or energy efficient cities on the world and especially European Union level (Concerto, Civitas, Urbact, Energy Cities, etc.) [http://www.eumayors.eu/about/related-initiatives_en.html]. Reconstruction, renewal or transformation projects can be the solution for urban quarters.

One of the most common sustainable urban development strategies is transformation of the city's quarters. Urban transformation projects are kind of solution for unplanned or unusable urban areas. It is physical transformation for existing building stock with new standards and also it provides better structure to public space and supply network. For developed countries like Germany, it is way to alter the unusable area with new technology integration and to mitigate the impact of climate change. For developing countries like Turkey, urban transformation projects change the physical environment and especially urban spatial structure and begin to control building standards. After having lost thousands of people in earthquake in the past, before even worse disasters hit the country, unplanned cities with buildings out of keeping standards should be transformed in Turkey.Transformation projects are significant for integrating strategies and aspects for energy management of authorities. It has big potential to integrate efficient resource and energy management principals, to minimize the urban enegy consumption and to adapt the renewable energy sources. Chief point for this energy transformation acts is that affordable and adaptable solutions should be determined for the urban sites. Sustainablity of the developing areas has to be considered for present and future users.

In urban projects, the steps and strategies are important for implement and handle the project as a result of the largeness of the area. If the project developer has an approach for different sites and it is applicable for different area, it can be used for various places. This research takes the common points for all urban transformation projects such as density, building property and possible renewable energy sources. It clarified the steps for this urban energy transformantion project and prose a practicable approach for the projects.

FACTORS AFFECTING THE URBAN ENERGY IN TRANSFORMATION PROJECTS

In the urban scale studies, to know the patterns of energy consumption is important for the management of supply. In the energy management works, it is easy to get information from supply but it is hard to define the requirement for different energy sources and the nature of users' requirements. This kind of energy information is significant for sustainable urban energy planning, for the reason that the energy supply needs to be on meeting energy users' needs in the best way possible. Urban design pattern mainly draw the city line and it shapes the inhabitant's comfort requirement or requests. On this level architecture or city planning doesn't have a comprehensive model which can be applied to every place and can take all factors on the account for developing sustainable cities or settlements. But we can define the main factors that affect the urban energy consumption and shape with urban design decision. These factors can be categorized as follows:

Urban density

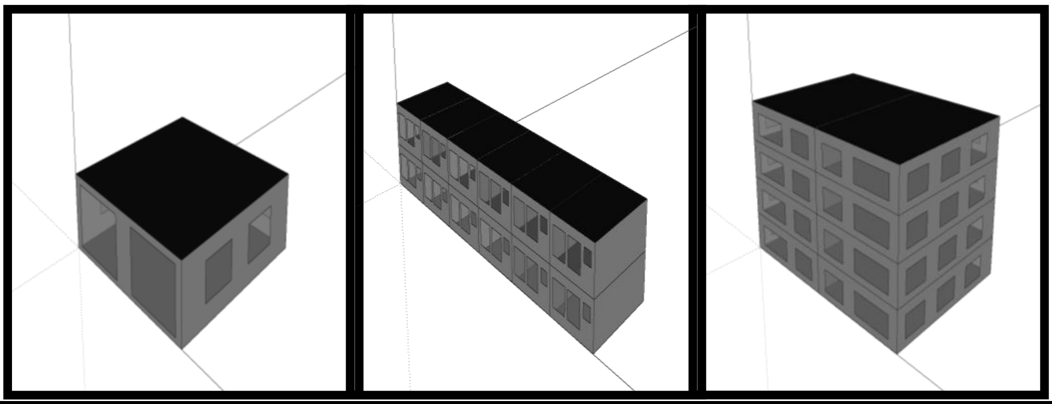
Rapid population growth brings with it, a growing need for built-up area which is one of main problems of the cities. Most of the time, this need is proved with high-rise buildings or compact settings, instead of expanding the boundaries. This brings the term of "urban density" which is used in urban planning and urban design to refer to the number of people inhabiting in a given urbanized area [Sokido and Bhaduri, 2013]. The urban density can affect the total energy demand of a city with different ways and these effects are complex and conflicting [Givoni, 1998]. Density sometimes can bring the benefits but it also creates extra loads and undesirable conditions. It affects the thermal performance, the natural lighting and ventilation possibilities of the buildings and these effects can either be positive or negative according to dominant climatic condition. On the other hand, the density supports to the district energy systems and besides that, the infrastructure facilities are shorter so it reduces also the energy requirement for pumping. Controversially, the energy requirement for pumping on the vertical direction is getting higher in the high-rise cities [Eicker et al., 2010]. The effect of density on heating, cooling and lighting energy demand of the areas is different and their influences are changing according to climatic conditions.

Characteristics of built environment

Physical properties of buildings and technologies in the building sector have a significant effect on the energy consumption. Insulation properties, windows type and area, the efficiency of technical appliances in buildings such as elevators, escalators, HVAC systems' equipments are profiled the building for evaluation of its energy. Building envelope, this is interface between outdoor environment and indoor conditions, works as a thermal barrier and serves a function in regulating a comfortable indoor temperatures. It plays a crucial role for reducing the need for heating and cooling of building. Moreover the placement of windows and doors, the size and location in the envelope has a significant role on the control of energy losses. Buildings should always be contemplated in the conjunction with their surroundings. In order to manage the use energy of the built environment in a sustainable way and to minimize harmful emissions, the performance of the city scale must be considered. Building energy condition can be characterized with urban pattern, building stock properties and also infrastructure possibilities. In the terms of shading and reflection, lighting and thermal energy loads are influenced by the architectural form of the urban structures and the neighborhood relationship.

Possible renewable energy source applications

Buildings are integrated into networks of overriding technical infrastructures which are water supply, drainage, sewerage, water disposal, electricity system, heating and cooling networks and transportation. The development of more sustainable cities critically depends on a style of urban infrastructure condition that encourages more efficient patterns of resource consumption. District heating or cooling in combination with energy efficiency measures in buildings account for approximately one third of the reduction of emissions [Särnholm et al., 2009]. Therefore, efficient supply system and integration of renewable energy technologies to the network are crucial for sustainable cities. On the other hand renewable energy integration is more meaningful solution at urban scale. Indivual building renewable energy integration is not factual answer for efficiency and feasibility. Renewable energy application on the urban area or district, which is directly connected to the grid so it eliminates transmission loss on the other hand it doesn't use any other land for application, has better energy performance than the individual applications. Solar PV or solar heating system integration on the roof has high potential with easy application. Façade integration has not easy for the underperformance of panels caused by the inequable shading. Wind tirbunes are not easy to implement to the urban district for the reason that it is affected from location of the building, wind direction, heights of surrounding buildings, other roof-top structures and so on.



Building type	One storey house	Row houses	Apartment block
Floor area	10.5mx10.5m	7m x10m	20mx14m
Height	3.5m	7m	10.8 m
Building unit	1 house-	6 houses	1 block-

Figure 1 (a) Energy plus model of one storey house (b) Row houses and (c) Apartment block

METHODOLOGY FOR PARAMETRICAL ANALYSIS

In the urban transformation projects, especially used for residential areas, highrise apartment form is used for restructuring the land in the furtherance of scalling up the recreation and green area opportunity. In order to limit the complexities related with real urban areas, the archetype was defined according to common typologies for transformation projects and this simplified type is used for energy performance simulations. There is not any survey for common building typology in Turkey but the German building stock was explored on the basis of energy demand properties and main residential building typologies defined by Institute for Housing and Environment-Germany (IWU, 2003). According to this research one storey, row houses and apartment blocks take into account for possible former building types of urban transformation area **as shown in Figure1.** According to profesionel point of view similar building forms are commonly used also in Turkey.

The apartment block with 10 storeys is chosen for possible new building form for urban transformation projects in Turkey and Germany. Floor area of the building is 24,4m*24,4m and height of it is 30m. Glazed area on the façade is 35% of the full façade area. Three dimensional urban quarter simulation was done for generic urban form **as shown in Figure 2.** The representative urban quarter constitutes of 9 generic building blocks and the distance between the buildings varies according to site density. The major orientation for the site design is the South. To see the total energy demand of the building, heating and cooling analysis including the annual electricity consumption with daylight responsive control was calculated in the Energyplus simulation program (simulation methodology has been described detailedly in the paper Kesten et al., 2011). Ankara and Stuttgart Energyplus weather data is used for the simulations.

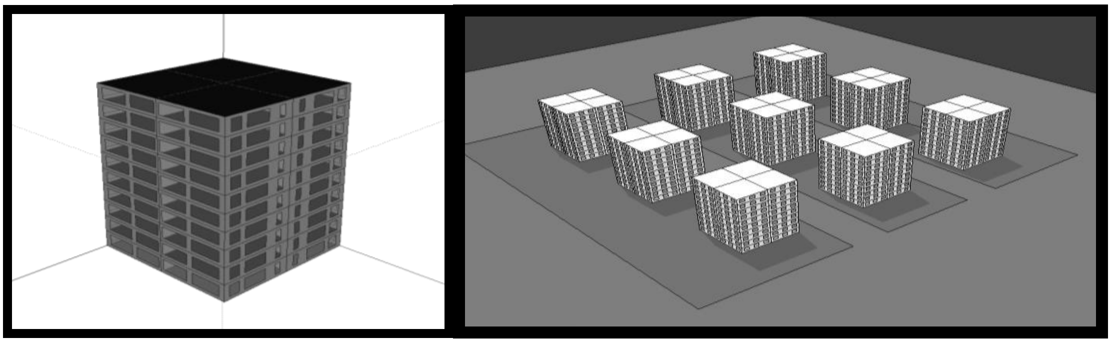


Figure 2 (a) Energy plus model of urban quarter and (b) Energy plus model of urban quarter according site density.

Table 1. U-values (W/m²K) of building envelope according to construction year and building energy standards (LE: Low energy standard, PH: Passive house standard)

Building Component	ANKARA			STUTTGART										
	1984	2000	2008	1948	1968	1978	1983	1994	2000	2007	2009	LE1	LE2	PH
Exterior walls	1.2	0.5	0.5	1.7	1.4	1.03	0.8	0.6	0.5	0.3	0.24	0.23	0.15	0.13
Floor	0.75	0.45	0.45	0.8	0.8	1	0.8	0.6	0.5	0.3	0.24	0.3	0.26	0.19
Roof	0.47	0.3	0.3	0.8	0.8	0.6	0.5	0.3	0.3	0.3	0.24	0.25	0.19	0.15
Windows	2.7	2.6	2.4	5.89	2.72	2.72	2.72	1.93	1.82	1.73	1.3	1.2	0.9	0.8

Occupation of the flats was simulated for an identical family scenario, consisting of 4 family members who are not home during the day except on weekends. The usage time of the appliances was configured according to the statistical data. Every house has television, computer, washing machine, dishwasher, oven, and fridge. The usage was determined as the average time taken from the German household statistic (Gruber and Schlomann., 2005)The EN ISO 13791 was taken as an input for internal gains from occupants. The lighting was defined as 13 W/m^2 and 40% of this is the convective gains. The heating set point was defined as 20°C and cooling set point was defined as 26°C. The heating system was shut down end of April to the end of October and while the cooling was operational for the duration of this time. The properties of building envelope are defined according to national standarts of the countries **as shown in in Table 1.** Simulation has been validated with measured data and it has been described detailedly in the paper Tereci et al., 2010. In the transformation project areas it is assumed that the former buildings in Germany can have been built before 1994 standards. Because of the unplanned development after 1980 in Turkey, the energy values of former buildings can be the worse than this results. But 1984 building standards are taken into account for building envelope which can be the best energy performance case for urban transformation project.

PARAMETRICAL ANALYSIS RESULTS

The heating, cooling, electricity and hot water useful energy demands for possible former building types were simulated without considering the effects of obstructions. These results are **presented in Table 2** and serve as a baseline for comparison. In the cold climatic condition like Stuttgart and Ankara, heating demand especially for residential houses is very important indicator for energy performance of the building.

Heating and cooling demand of the building types in different dense areas were evaluated to get an understanding of the site density effect. **Figure 3 shows** the heating and cooling demand of the former building types located in the centre of an urban block with function of site density densities which were constructed in 1984. Without any shading effect the heating consumption of one storey house is 106.5 kWh/m^2 while depending on the shading of the area the heating consumption can be 12% higher in Ankara climatic condition. The energy demand of apartment block is less by compare with one family house and row houses for both climatic conditions. Site density is affected less in Stuttgart by 8% for one family houses. Especially for cooling loads site density was highly affected in Ankara conditions and coillings loads decrease nearly 50% for all type of buildings.

Table 2. Dynamic simulation results of former reference buildings (construction year 1984) without surrounding obstructions

Reference Buildings	Ankara			Stuttgart		
	Heating	Cooling	Electricity	Heating	Cooling	Electricity
One Family House	106.53	19.44	30	101.53	6.03	33
Row Houses	98.63	15.38	18	94.01	2.82	19
Apartment Block	61.82	19.2	21	62.77	6.87	23

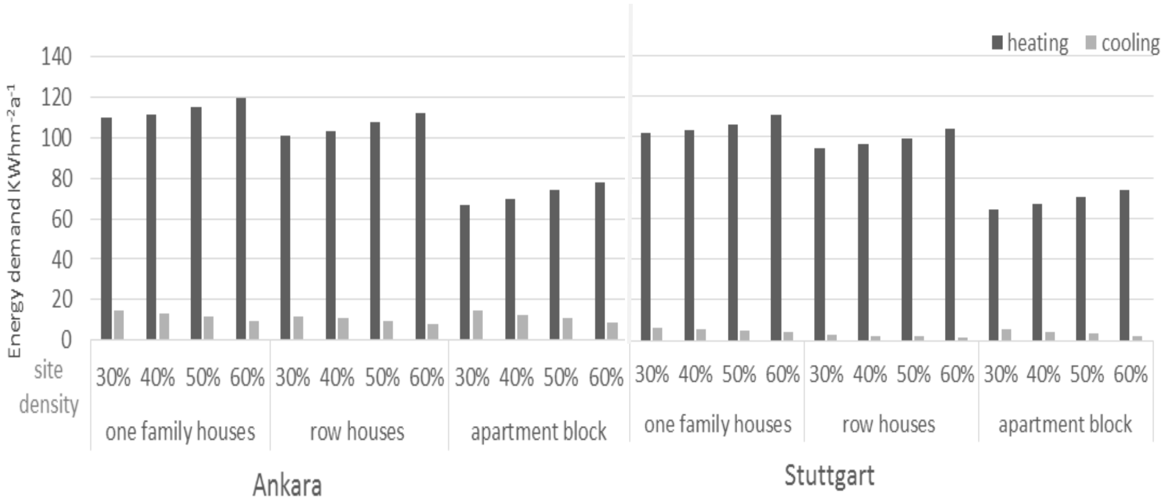


Figure 3 Heating and cooling energy demand of building types with site density

As mentioned before, physical properties of buildings have a significant effect on the energy consumption so the building envelope properties according to energy standards or codes are profiled the building for evaluation of its energy. To understand the effect of energy standards on the buildings, reference buildings are simulated according to different construction years. **Figure 4 presents** the energy demand of eleven versions of apartment block according to different energy standards in Germany since 1948. The passive standard buildings show the heating demand without heat recovery from exhausted ventilation air. Similar trend is observed for one family house and row houses. It is not possible to mention or calculate for Turkey another building envelope properties because of the lack of the energy standards. We can assumed that the buildings which were built before 1984 are in the worse than these conditions and Germany example can have an idea about the effect of thermal properties of envelope. According to results, building standards in 1994 has given a jump for the energy performance of buildings and we can say that for urban transformation project for both countries, the energy performance of the site can be enhance at least 30% for the buildings constructed in the year before 1994.

It is also important to decide for new construction area density for urban transformation project. Therefore ten storeys apartment block which is constructed with current energy standards (Turkey 2008, Germany 2009) was evaluated according to site density and the results are presented **in Figure 5**. The heating consumption of the blocks is 53 kWh/m^2 and cooling demand is 10 kWh/m^2 in Stuttgart. The heating consumption of the blocks is 55 kWh/m^2 and cooling demand is 16 kWh/m^2 in Ankara. Depending on the shading on the site, the heating demand can be 25% higher more and the cooling demand can be 40 % less than the building without shading.

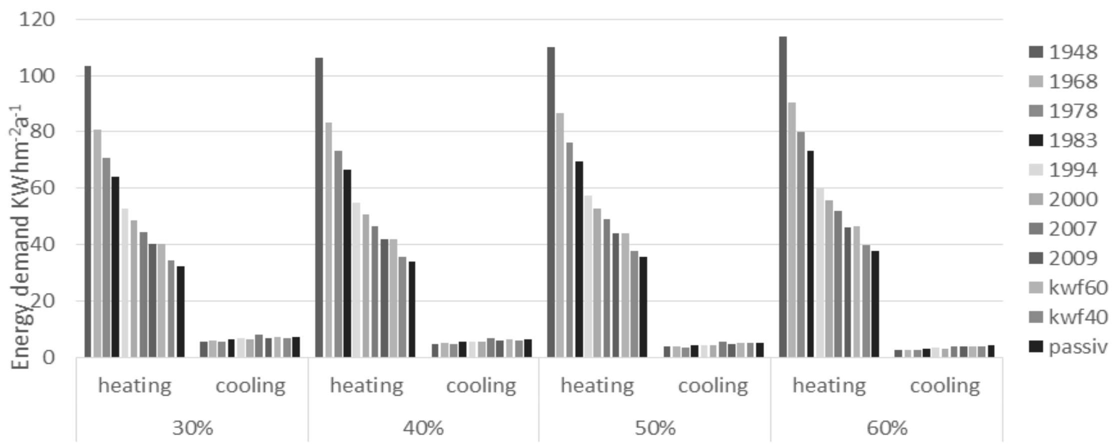


Figure 4 Heating and cooling demands of the ten storey apartment block in Germany with different site densities and envelope properties.

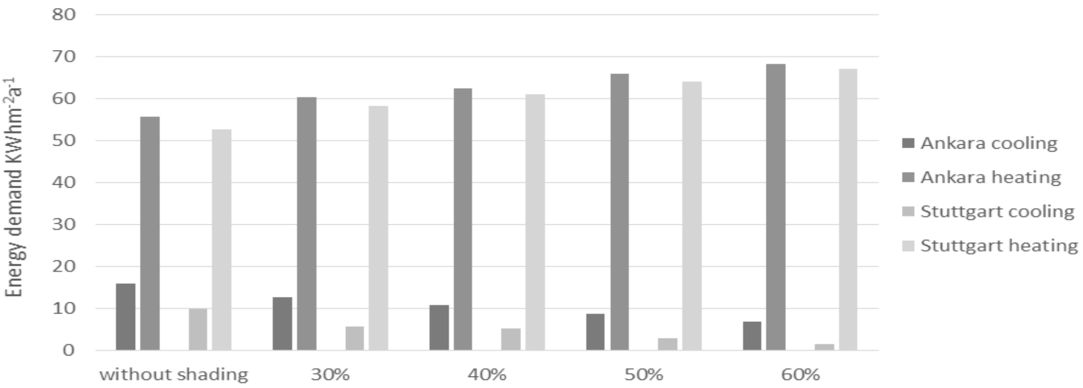


Figure 5 Heating and cooling demands of the ten storey apartment block constructed with current energy standards for Ankara and Stuttgart climatic conditions within different site density.

According to the reference building results, it is not easy to compare the site energy performance. Therefore the site performance of the new and former buildings was evaluated according to the same size urban districts and equal densities. Depending on the building typology chosen, the number of buildings, and therefore the number of housing units and their occupancy will vary. For each building type, the heating and cooling demand of the whole site was simulated at a density of 40% for Stuttgart. These figures are presented **in Table 3.** The average heating demand of ten storeys apartment block for urban transformation project is 60 kWh/m^2 while the average heating demand of one family house is 105 kWh/m^2, row houses' is 98 kWh/m^2 and apartment block with 4 storeys' is 68 kWh/m^2. The urban transformation project can reduce the heating demand up to 43% and it has the similar positive effect on the cooling demand of the site. In Ankara, the average heating demand of ten storeys apartment block for urban transformation project is 58 kWh/m^2 while the average heating demand of one family house is 114 kWh/m^2, row houses' is 105 kWh/m^2 and apartment block with 4 storeys' is 72 kWh/m^2. Reduction on the heating demand by urban transformation project can be 50% and also cooling demand reduction can be seen up to 28%.

In this study, supply scenario an electric heat pump with a COP of 4.0 was chosen as a standard heating system solution, covering 80% of the heat demand, supplemented by a gas condensing burner with 96% efficiency. Cooling was provided by an electric chiller with a COP of 3.0. Also, auxiliary electrical energy for pumping as well as delivery distribution losses of 10% of the heating and cooling demand was added. According to the CO_2 emission factor for natural gas was 0.202 t CO_2/MWh and for electricity 0.539 t CO_2/MWh, per capita CO_2 emissions is calculated. The lowest primary energy demand is ten storey apartment block for urban transformation project but lowest per capita CO_2 is the old apartment blocks.

Table 3. Heating and cooling energy demands of an urban area with 40% site density for different building types

	Number of buildings	**Flats**	**Conditioned floor area/m^2**	**Total heating energy demand/ MWh**	**Total cooling energy demand/ MWh**	**Average primary energy demand (kWh/m2)**	**CO_2 emission /t CO_2**	**CO_2 emission per capita/t CO_2 cap−1**
One family house	88	88	8800	926	61	115.5	176	0.5
Row houses	21	147	20580	2010	596	107.5	378	0.64
Apartment block	31	372	34720	2353	202	87	494	0.33
Apartment block (urban transformation)	14	560	83342	5034	283	79	1291	0.58

In the urban transformation project to add some renewable energy sources to the site is easier than the implemention to former buildings by reason of orientation, construction conditions, shading and etc. It is possible to add some district heating system for both cities and also this system can be combined with cogeneration plant, geothermal heating or central solar heating system in the urban transformation project. These systems can reduce high amount of carbon emissions and burning fossil fuels. For determining the performance of a PV system for the buildings in Ankara and Stuttgart, it was considered that the whole roof area of the buildings would be used for a free standing PV-installation with a tilt angle of 25°. PV-fields with for this example chosen 44 Sunpower SPR-305-WHT panels each, oriented to South. Each PV field was arranged to 4 strings of 11 PV-panels each which are connected to one inverter. The total collector fields and two inverters with a nominal power of 29.34 kW and a power ratio of 1.18. The average energy yield of the system is 34.2 MWh/a for Stuttgart and 48 MWh/a for Ankara. It is possible the produce 25% -35% of the consumed electricity with these installations.

CONCLUSION

The total energy consumption of the cities is crucially influenced by urban design decisions. This study shows that the site density and physical properties of buildings have significant effects on the site energy performance so this kind of evaluation should be made before the design of refurbishment of old settlements area. It is difficult to make the recommendations for all cities since they have unique characteristic and context but according to building standards and density decisions can provide big key for energy management of the cities. There is notable connection between energy demand and the urban site planning. Definitely instantaneous energy demand of the city is highly affected from the energy usage behavior of citizens and operation of the system but statistic mode of energy consumption may give design criteria for energy management decisions. Hovewer in addition to that, the climatic conditions and the population of the area, building typology and the density should be analysed carefully before the urban transformation projects.Detailed dynamic thermal simulations show that 10-20% heating and cooling demand may be saved by an energy aware site planning.

Beside that, renewable energy applications should be integrated in the urban planning process at the beginning in order to maximise the use so the urban transformation projects also have a big potential for integrating the renewable sources. According to this study, there is a big potential to save more than 30% of the energy used with renewable energy integration. This study covers only project site decision for urban transformation projects but better renewable energy integration can be done with district planning.

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Multifunctional Glazing System- Solution for Modern Smart Glazing

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ABSTRACT

Multifunctional glazing combines various glazing, that have potential to control solar heat gain by changing the window transmittance and low heat loss. In autonomous multifunctional glazing its function will be powered by PV layer attached to the glazing. This glazing obviates the necessity for shading devices to control the glare. Glare control for such a small scale south facing vertical surface multifunctional glazing is discussed.

INTRODUCTION

The building sector consumes 41% energy in USA, 40% EU, and 25% in China. At present, low energy buildings are gaining importance to reduce overall energy demand. A near zero energy building combines two concepts (i) the amount of energy supplied to the building must be small and (ii) that energy should be supplied from the renewable sources. In this context, windows are the most important building envelope component contributing to energy use reduction. Windows offers privacy, visual amenity, comfort and control of light and air. In a direct dynamic relation with outside atmosphere, heat gain and heat loss both ensue through a window. In addition to multiple pane glazing that includes low emittance coatings vacuum glazing, aerogel glazing, building integrated photovoltaic (BIPV) glazing and smart glazing are available. Vacuum and aerogel glazing gives low heat loss from room to environment and reducing heating load demand. BIPV glazing introduces daylight and reduces the artificial lighting load demand. Smart glazing like electrochromic (EC), liquid crystal (LC), suspended particle device (SPD) type control the solar heat gain and reduce the cooling load demand.

Vacuum glazing consist vacuum between two glass panes separated by small pillars to withstand the atmospheric pressure and insulated hermetic edge sealing around the periphery of the two glass sheets. This glazing shows total heat transfer coefficient (*U* value) values between 0.5-0.9 W/m^{2}K (Robinson and Collins 1989; Collins and Robinson 1991; Fang et.al. 2006). Highly insulating vacuum glazing can be achieved using hermetic edge sealing around the periphery of two glass sheets (Collins and Simoko 1998). Addition of transparent low emittance coatings reduces radiative heat transfer between the sheets. Use of two low- e coatings does not reduce the overall heat transfer rate over a single low e coating layer. Using one layer of low e coating also reduces the overall system cost as low e coatings are costly (Fang et.al. 2007). An aerogel is a translucent solid gel that exhibits high thermal insulation, low refractive index, and very low density (Jensen et.al. 2004). This glazing filled with aerogel can achieve a heat loss coefficient less than 0.7W/m^{2}K for 15 mm thick aerogel between two glass panes (Schultz and Jensen, 2008; Schultz et.al. 2005). In BIPV glazing transparent or semitransparent solar cells are placed on the outer facing surface of the glass panes (Miyazaki et.al. 2005, Chow et.al. 2009) which can be used as small scale electricity generation, control solar heat gain and transparency of visible light. In case of electrochromic glazing electrochromic material are placed between two glass panes. An electrochromic material is cell which changes its state from transparent to opaque state by redox reaction in the presence of applied D.C. voltage typically 0 to 5 V (Rosseinsky and Mortimer 2001). The optical properties of EC can be reversed by simple inversion of electrical polarity (Lee et.al. 2003, Granqvist 2012). The speed of this colour change process decrease at higher ambient temperatures. The bleaching to colour process take more time than colour to bleach process. EC material has potential to control transmissivity, absorptivity, reflectivity and emissivity of a glazing (Granqvist et.al.2003; Granqvist 2005). Electrcochromic glazing controls solar heat gain and daylight through a window by blocking the transmission of near infrared (NIR) and visible light (Pennisi et.al. 1999, Granqvist 2000). SPD and LC both work on AC power. Both types become clear when continuous power supply is available and a switched off condition generates an opaque state. Compare to EC glazing LC and SPD switch on response is very fast, within 2 -5ms. Another advantage of these two glazing are they produce equal transparency all over the glazing specifically when the glazing size is larger (more than $1m^2$). EC glazing colouration process takes 5-10 min depending on the size and sometimes the coloration is not uniform. The required electrical power consumption for EC glazing is much lesser than the LC and SPD glazing.

Building occupant prefer to live and work in space with good daylight distribution. Daylight in a building is preferable to saves energy from artificial lighting. Discomfort glare arises from a high or non-uniform luminance distribution with high contrast luminance between source and surroundings. Discomfort happens due to glare sources position, the part of sky seen through and the size of glare sources (Galasiu and Atif 2004; Nazzal 2005). Controlling glare while achieving maximum utilisation of daylight is one the most difficult task for present available window and shading devices. Different shading devices such as external shading, internal shading, and louvers are used to control daylight and glare (Ahmed, 2012; Freewan, 2014). Particularly overhang type shading devices cannot control the glare created from low azimuth angle direct solar radiation. Switchable glazings are capable of reducing this glare.

CONCEPT of MULTIFUCNTIONAL GLAZING

Combining vacuum and EC device gives both low heat loss and switching characteristics to get both effects together (Papaefthimiou et.al. 2006; Fang et.al. 2008). An EC /LC/SPD device needs an external supply to change colour which can be supplied by PV added to the EC (Deb et.al. 2001; Huang et.al. 2012; Huang et.al. 2012). Using EC window and overhang shading in combination (Lee and Tavil 2007) has been studied.

A new multifunctional glazing, shown in figure 1 integrates of all these different existing EC/LC/SPD system, Vacuum/Aerogel, and Photovoltaics (PV). PV generates the power necessary to change the colour of smart material (EC, LC, and SPD). Multifunctional glazing can be solution for new fenestration devices that control the direct solar radiation, improve daylight quality, control daylight and glare. The location of PV layer will have an influential contribution in multifunctional glazing. Different positions of the PV layer will produce different PV outputs that will be used to switch the smart material.

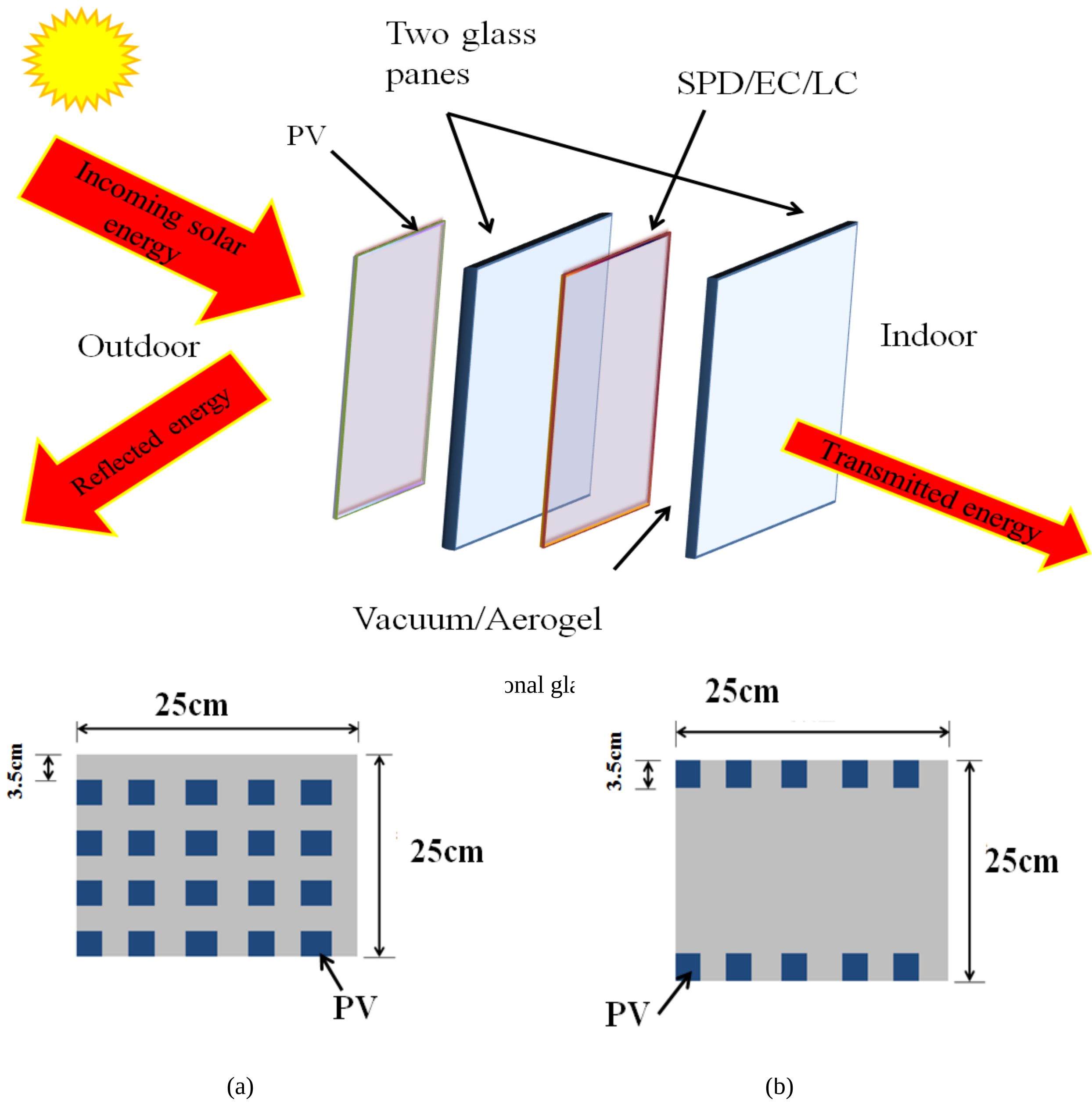


Figure 2 Schematic diagram of semitransparent PV device for multifunctional glazing

Transparency reduces when PV cells are applied to the glass. Organic PV cells have a high transparency compare to inorganic PV cell but durability and efficiency of this type of cells are very lower. Keeping in consideration the cost and durability of the PV cells, silicon PV cells are considered in this study. Figure 2 illustrated two different options of placing PV cells are placed to glazing space to provide a semitransparent glazing. In the figure 2 (a) shows a 20% transparency while figure 2 (b) has 40% transparency. For the multifunctional glazing as shown in figure 1 different transparency level of each and layers are , glass 90%, PV 20% or 40%, EC clear 50% , EC opaque 10%, SPD opaque 5% and clear 58%. Different positions for the PV will result in different PV outputs available for switching the multifunctional window. PV arrays produce maximum power when inclined at the local latitude angle. As windows are usually vertical surfaces most the PV will also be inclined vertically. Depending on the different position of window east west south north the incident solar radiation intensity will also be different. It will be evaluated that how much light and solar radiation will be available for multifunctional glazing and also for different orientation.

Different possible positions of different layers are;

Type 1- Glass, SPD/EC/LC, PV, Vacuum/aerogel, and Glass (here we consider only EC, PV 20% transparent)

Type 2- PV, Glass, EC/LC/SPD, Vacuum/aerogel, and Glass

Type 3- EC/LC/SPD, Glass, PV, Vacuum/aerogel, and Glass

Type 4-PV will be on the frame of glazing, Glass, EC, Vacuum/aerogel, and Glass

This Study considers Type1

METHODOLOGY

Glare index calculation is provided for a 25cm ×25cm multifunctional glazing for a sunny day on 1st of June 2014 in Dublin (53.3478° N, 6.2597° W). The glazing is considered to be on a vertical south façade. Dimension of the room and glazing position and measuring points are shown in figure 3.

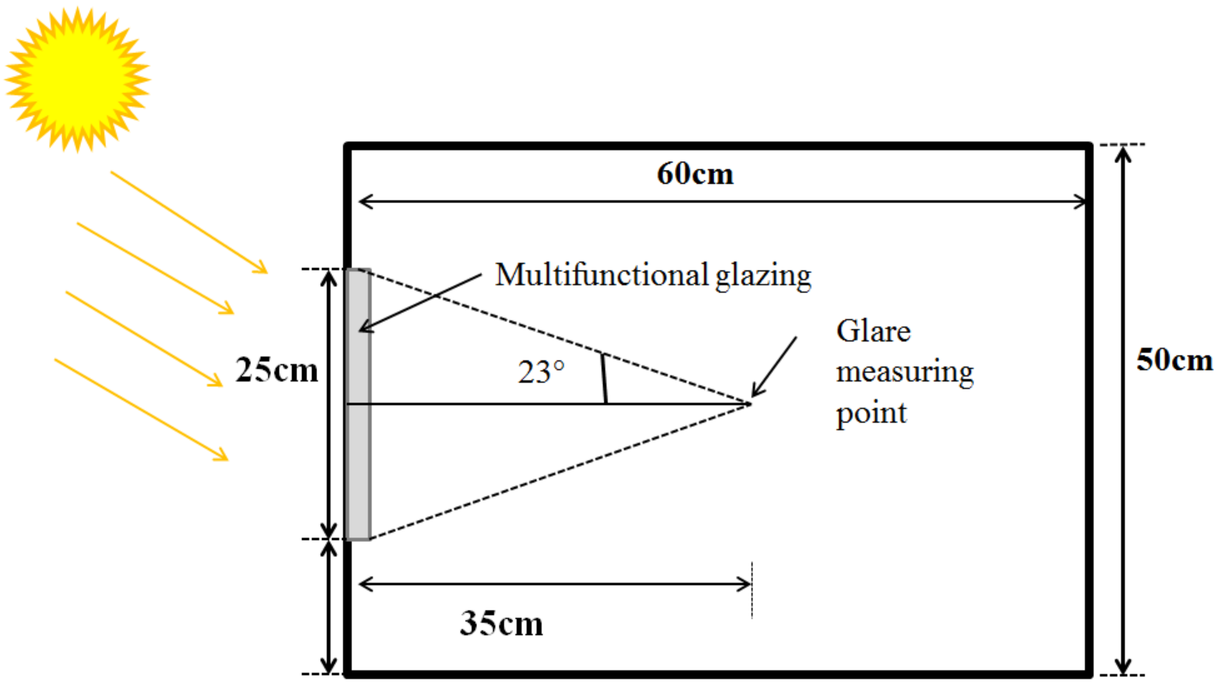


Figure 3 Schematic cross section of a room with multifunctional glazing place on vertical south facade

The available solar radiation I_{g20} inside the room will be

$$I_{g20} = \tau_{g1}\tau_{pv}\tau_{ec}\tau_{vaccum}\tau_{g2}I_{vinci} \tag{1}$$

Solar radiation incident on the vertical surface is calculated from horizontal direct and diffuse solar radiation using equation 2 (Liu and Jordan, 1960) for vertical surfaces orientated, east, west, north and south.

$$I_{vinci} = I_b R_b + I_d R_d + \rho R_r (I_b + I_d) \tag{2}$$

$$R_b = \frac{\cos\theta_i}{\cos\theta_z} \tag{3}$$

$$R_d = \frac{1+\cos\beta}{2} \tag{4}$$

$$R_r = \frac{1-\cos\beta}{2} \tag{5}$$

Angle of incidence are given by

$$\cos\theta_i = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega \tag{6}$$

Global illuminance from the global incident solar radiation can be calculated from (Perez, 1990)

$$L = I_{vinci}\left[a_i + b_i W + c_i\cos(Z) + d_i\ln(\Delta)\right] \tag{7}$$

Discomfort glare is represented by glare index (GI) described by (Hopkinson and Collins 1970; Hopkinson and Bradley 1960)

$$GI = 10\log_{10} 0.478\left(\frac{L_s^{1.6}\Omega^{0.8}}{L_{ba} + \left(0.07\omega^{0.5}L_s\right)}\right) \tag{8}$$

The standard glare values are 10 for just perceptible, 16 for just acceptable, 18.5 for borderline between comfort and discomfort 22 for just uncomfortable and 28 for just intolerable.

RESULT & ANALYSIS

Vertical surface global solar radiation is illustrated for different orientation in figure 4. It can be seen that receiving solar radiation on multifunctional glazing is possible during all the day in south facing building. East facing and west facing glazing receive more solar radiation before 12 am and after 12am respectively. For an East facing window in the morning variable transmission control of glazing is essential whereas west facing windows needs control in the afternoon. South facing window needs maintenance of glare and daylitghiting throughout the day

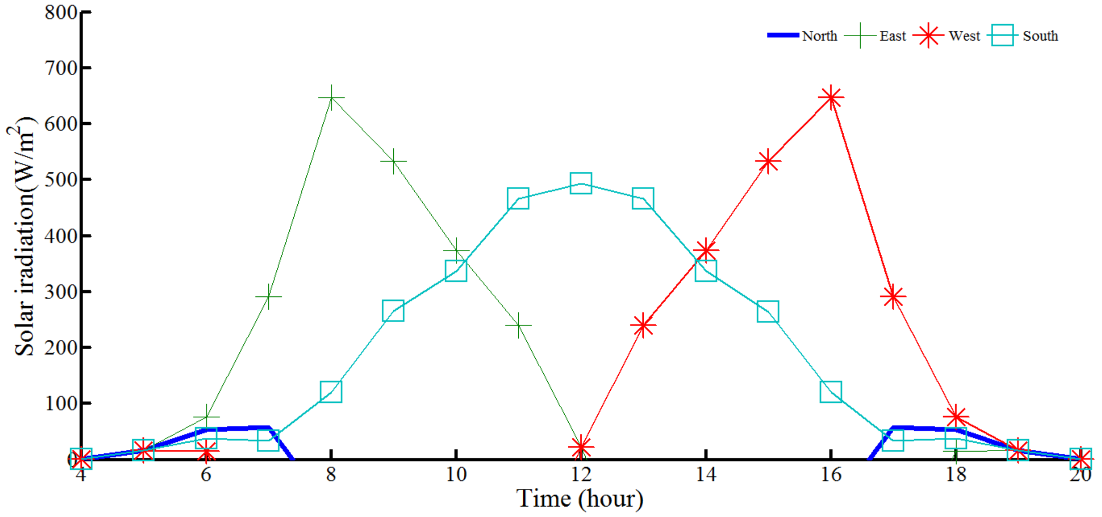
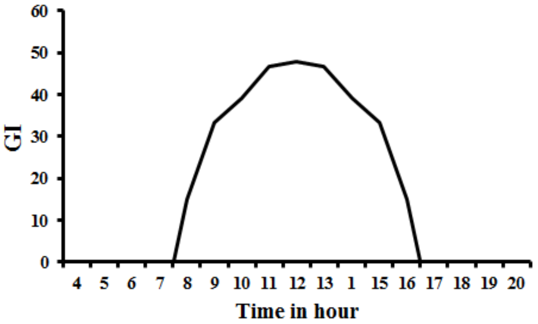
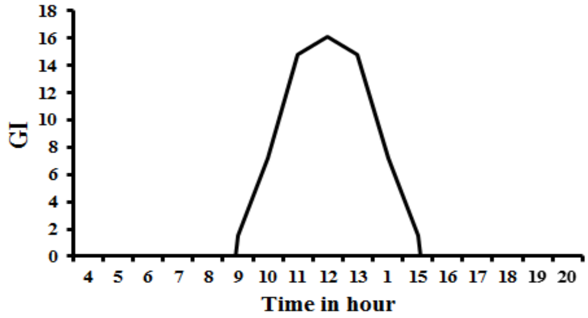


Figure 4 Incident global solar radiations for north east west and south on vertical surface

Glare index (GI) for south façade multifunctional glazing for switch off and switched on conditions are shown in figure 5. When EC was switched off its 50% transparency allowed excessive light inside the room. It can be seen that after 8am it crossed the limit of intolerable limit range of 28. At 12am it was nearly 50. This excessive glare can be controlled using the switched on EC with10% transparency rendering the glare acceptable range. At 12 am the maximum glare was 16 just in the acceptable range. In both case the PV transparency was 20%.



(a)



(b)

Figure 5 Glare indices when EC was switched off clear (a) and switched on opaque condition (b)

CONCLUSION

Multifunctional glazing has potential to control heat loss and heat gain and generate electricity to switch a switchable material. This glazing has the potential to control glare. Glare control of a particular room has been found to be provided was theoretically calculated using standard glare index equation. It was found that when EC device was switched off condition the glare was nearly 50 at 12 am which was more than intolerable limit of 28. During the switched on condition the glare was nearly the acceptable range 16 at 12 am.

NOMENCLATURE

I = Incident solar radiation (W/m^2)
τ = Transmittance
L = luminance (lux)
R = conversion factor
Ω = solid angular subtense for modified position index (sr)
ω = solid angular subtense for source (sr)
ϕ = latitude angle (deg)
δ = declination angle (deg)
β = title angle (deg)

Subscripts

T = vertical
b = beam
d = diffuse
s = source
ba = background
r = radiative

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Environmental Performance of Adaptive Building Envelope Design: Urban housing in Seoul, Korea

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ABSTRACT

Since the first construction in 1962, apartment housing represented modernity and quickly became a ubiquitous urban housing typology in the midst of Korea's rapid economic growth. Prominently influenced by the 1930s rational architecture from Europe, the housing site planning for Seoul systematically multiplied into a linear urban pattern of slab typologies. As the city stepped into the 21st century, the old slab typology—criticized for their lack of diversity and low density, adapted a new housing model from North American urban residential schemes—the mega glass tower. Energy consumption of the new tower typology has doubled from the linear slab model due to the increase in glazing ratio, the application of tinted green double glazing in replacement of clear double glazing, and the irregular orientation of the floor plans. This research analyzes the environmental performance of the new tower typology in comparison to the previous slab typology with the objective to improve the quality of future urban housing design and planning in Seoul.

INTRODUCTION

1930s rational architecture from Europe prominently influenced the housing site planning for Seoul, which systematically multiplied in a linear urban pattern. Consequently, typical urban housing layout in Seoul has the characteristics of expanding horizontally or orthogonally in clusters. These forms of clusters follow a linear, single orientation, slab configuration which conceptually provides a level of equality in housing that is in line with early ideas of modernity in the realm of architecture (Kang, 2004, p. 144-146). From a practical perspective, each unit could receive an equal amount of daylight, cross ventilation, and views outward within this system. This idea of equality, despite its formation of unity in the residential sector, simultaneously erased local identities of neighborhoods to the point where eventually every development appeared the same as the other throughout the entirety of the city.

Figure 1 1960s to 1990s Old slab typology apartment housing in Seoul, Korea.

Quite recently this linear apartment development strategy and residential culture have come under critical scrutiny. As the city stepped into the 21st century, the slab typology has been criticized for their lack of life quality, diversity, and dynamic urbanism. The old slab typology building can no longer provide the high density required by the city and create a healthy urban living environment. Developments from the 1960s to 70s remain in poor condition until the point of demolition (Kang, 2004, p. 143). As a reaction, from the demand for housing supply and its heavy reliance on the market, the scale of developments has increased to the mega glass tower. This residential tower typology of higher density is a model adapted from contemporary North American urban residential schemes. The tower simply as a typology has decreased the quality of residential living furthermore, in terms of creating a variety of housing clusters on a block and integrating with the urban built environment and community. Thus, a successful housing model does not exist yet in the city.

Figure 2 New tower typology highrise housing preconstruction sales in Seoul, Korea.

This research determines to analyze the environmental performance of the new tower typology with the objective to improve its quality in terms of architectural design and energy consumption through the building's envelope. Further examination of the relationship between the building envelope and environmental impact of the urban layout provides insight for sustainable housing developments in Seoul.

BASE CASE STUDY: SLAB TYPOLOGY ENERGY PERFORMANCE

The typical slab housing typology constructed from 1960s to 1990s, were built to the height of 8-10 story as multifamily mid-rises with one or two vertical circulation cores servicing all the residents of the building. This typology allowed for each unit to have a double orientation towards north and south, guaranteeing a sufficient amount of daylight, cross ventilation, and solar gains.

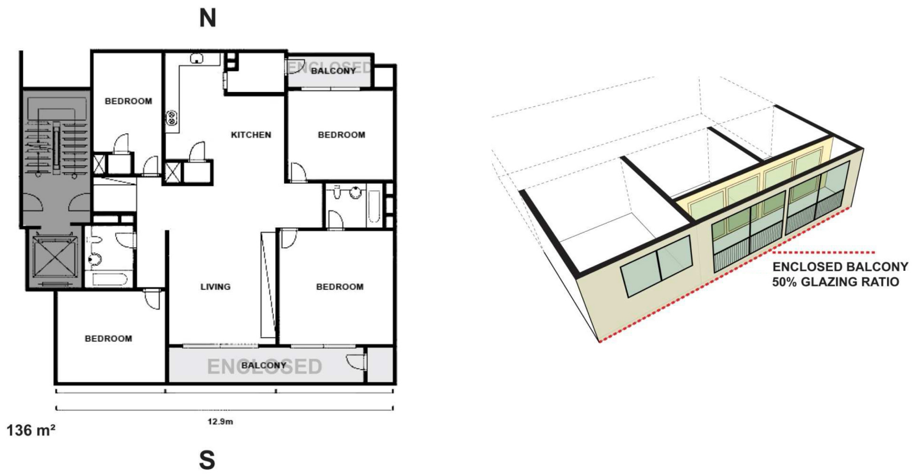

Figure 3 Floor plan of the old housing type used in the base case study and diagrammatic depiction of the enclosed balcony.

An old slab typology flat of 136m² was studied as a base case. It was constructed in the early 1980s and had been planned for demolition in the near future by the developer into new residential buildings. When examining a typical floor plan from the slab typology, two important characteristics of the layout are the open kitchen to living room floorplan and the enclosed balcony spaces to the south and north exposures. The open plan layout is crucial for effective natural cross ventilation during the humid months of July and August. The distribution of internal gains from the kitchen is an insignificant amount according to the occupant, but still a diminutive contribution to the internal temperatures as an auxiliary source of heat.

The enclosed balcony spaces function as buffer zones that control heat loss during the winter and also have the purpose of solar protection in the summer season as overhangs or cantilevers. The balcony of the slab typology is typically a glazed area of 50% to the façade area, detailed with two sliding window apertures that open 50% horizontally. The exposed south vertical surface of this flat in the base case study also has a 50% glazing ratio to the façade. Clear double glazing is used on the apertures to the exterior as well as to the glazed interior sliding partitions that divide the balcony from the interior living room space. The advantages of controlling heat loss as a buffer space, and storing the captured solar gains to the flat is a key factor found in the floor plans of the old slab typology.

Climate Condition of Seoul

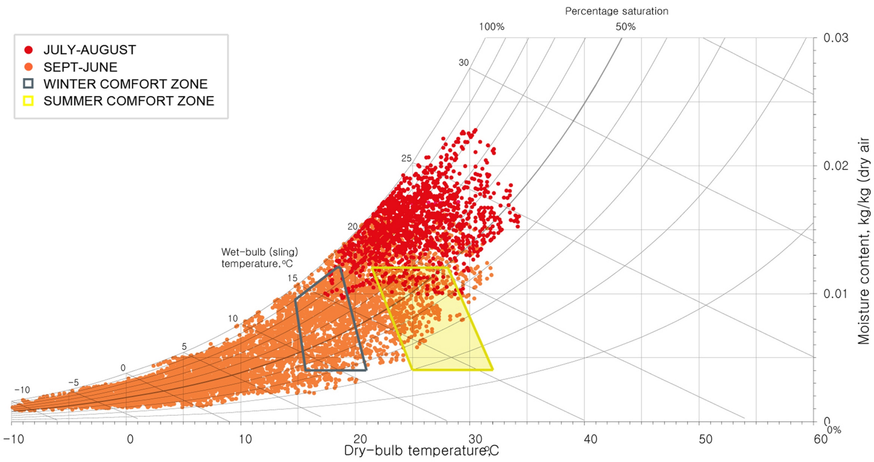

Figure 4 Psychrometric chart defining the summer and winter comfort zones (Szokolay, 2007).

The comfort band calculated from the equation, Tn = 17.8 + 0.31 x To, defines the summer comfort band range between 23 °C and 28 °C. The winter comfort band ranges from 17.5 °C to 20.5 °C. From the psychrometric chart, the red points plot the months of July and August. The relative humidity levels are high throughout the entire year but only falls outside the boundaries of comfort when the external temperature starts rising in the summer months of July and August. The yellow boundary defining the summer comfort zone shows that for the majority of July and August are outside comfort limitations. Consequently, cooling load consumption is also the highest during this period of discomfort due to this relative humidity level.

BASE CASE STUDY: TOWER TYPOLOGY ENERGY PERFORMANCE

Urban housing in Seoul has changed drastically since 2000 in terms of typology, construction, design and not absolutely for the better. The market demanded for housing with significantly higher density as the city became over populated. As a consequence, office-tower type urban residential models found common in North American cities (i.e. New York City, Los Angeles, and Chicago) were adapted into the residential sectors of Seoul. These towers satisfied the market's new density demand and provided diversity in the design of the floor plans (in comparison to the simple slab floor plates), in its irregularity and asymmetry. Each unit found more variety in the layout of the interior spaces and orientation towards the city. But these deeper tower plans have appeared to create new problematic environmental issues. The new tower typology unit which is analyzed closely as a case study is a corner unit of 132m² exposed to both south east and south west. Most of the units within the towers have lost the benefits of natural cross ventilation and north-south orientation of the old slab model. Externally the tower typology has not been able to address its contribution to the urban fabric of the city in providing an improved open space. In fact, the quality of the open space is in greater threat of diminishing due to the height and higher obstruction angles created by these mega towers.

Urban living in a dense city such as Seoul is a constant fight for more space. Due to the desire for maximizing floor sq meters for liveable space, the previous enclosed balconies have been erased for maximum floor sq meter and consequently the envelope has become a 100% fully glazed façade. From the post occupancy evaluation with the family, most discomfort was expressed during the summer months for overheating, weak natural ventilation, and high bills for cooling. In the tower typology base case, poor operable aperture on the glass façade with a small area of merely 0.84m² which tilts outward with a maximum angle of 30°, is a hindrance to the performance of natural ventilation.

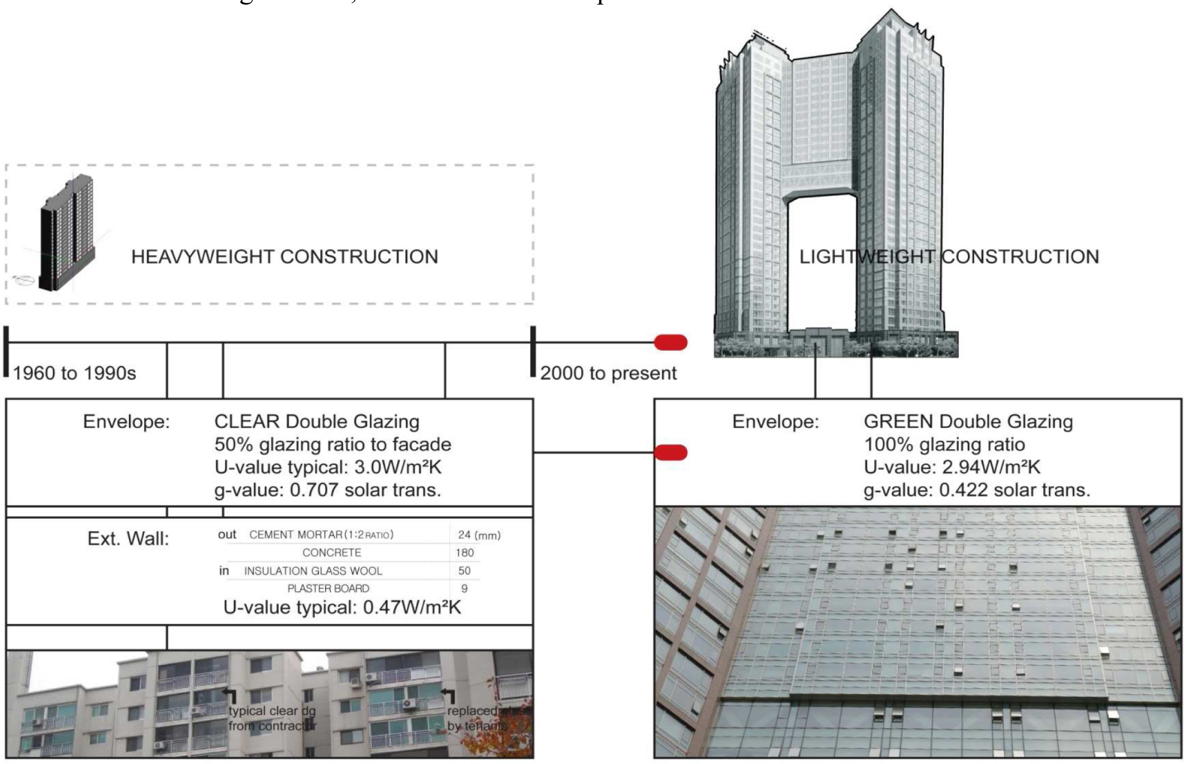

Figure 5 Construction standard comparisons between base cases of the old slab typology and the new tower typology (Jang, 2002).

Glazing Type and Thermal Performance

An essential difference between the two typologies is found in the envelope of the building. In terms of construction, the heavyweight construction of the old slab typology has transformed into lightweight construction in the new tower typology. The external wall of the slab typology had a typical U-value of 0.47W/m²K—concrete load bearing wall construction with insulation placed on the inner side of the wall. In the old slab model, the envelope of the building had a 50% glazing ratio to the façade. This ratio increased nearly to 100% in the new towers. Clear double glazing with a standard U-value of 3.0W/m²K and solar transmittance g-value of 0.707 has been replaced with tinted (commonly green tint) double glazing with a solar transmittance g-value of 0.422. The tinted glass has become a conventional strategy by contractors for urban housing to accommodate the increased glazing area and reduce overheating. In the new tower typology base case, poor operable aperture on the glass façade with a small area of merely 0.84m² which tilts outward with a maximum angle of 30°, is also a hindrance to the performance of natural ventilation.

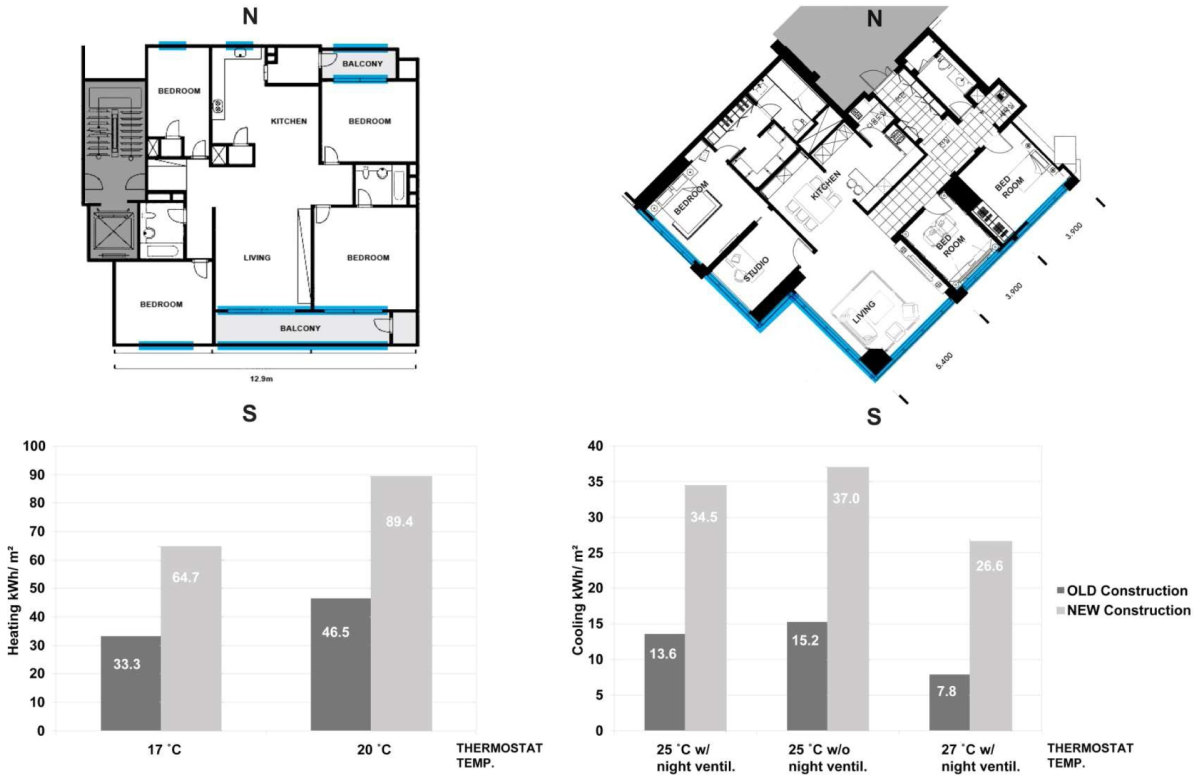

Figure 6 TAS simulation results show that the new tower typology unit has multiplied in annual heating and cooling consumption by approximately 50% in comparison to the old slab model. Previous research data collected from various organizations such as, the Korean Solar Energy Society, Seoul National University of Technology, and Korea Institute of Energy Research Department showed thermostat temperatures set at 20°C for winter heating simulations and 25°C for summer cooling. Both units are 136m² and 132m² in floor area, similar in the layout of the interior spaces, and with the same occupancy.

Impact of Obstruction by Urban Layout and Energy

An important issue to deal with is the urban planning of the new tower typology. What environment or context should the tower be in? A repetitive distribution motivated by careless market driven developments will lead to the identical banality created by the old slab typology. Urban planners and city authorities must have a higher awareness to prohibit monotonous, simply cost-saving development. The sheer height of the new typology creates a greater challenge in terms of integrating with the urban fabric at the ground level. Environmentally, the longer overshadowing of neighbour buildings and the open outdoor spaces must be taken cautiously into consideration during the early urban planning stages.

Figure 7 Aerial photo depicting the urban layout of the old slab vs. the new tower typology. The typical urban canyon of the old slab typology in Seoul was a 1 to 1 ratio of height to width.

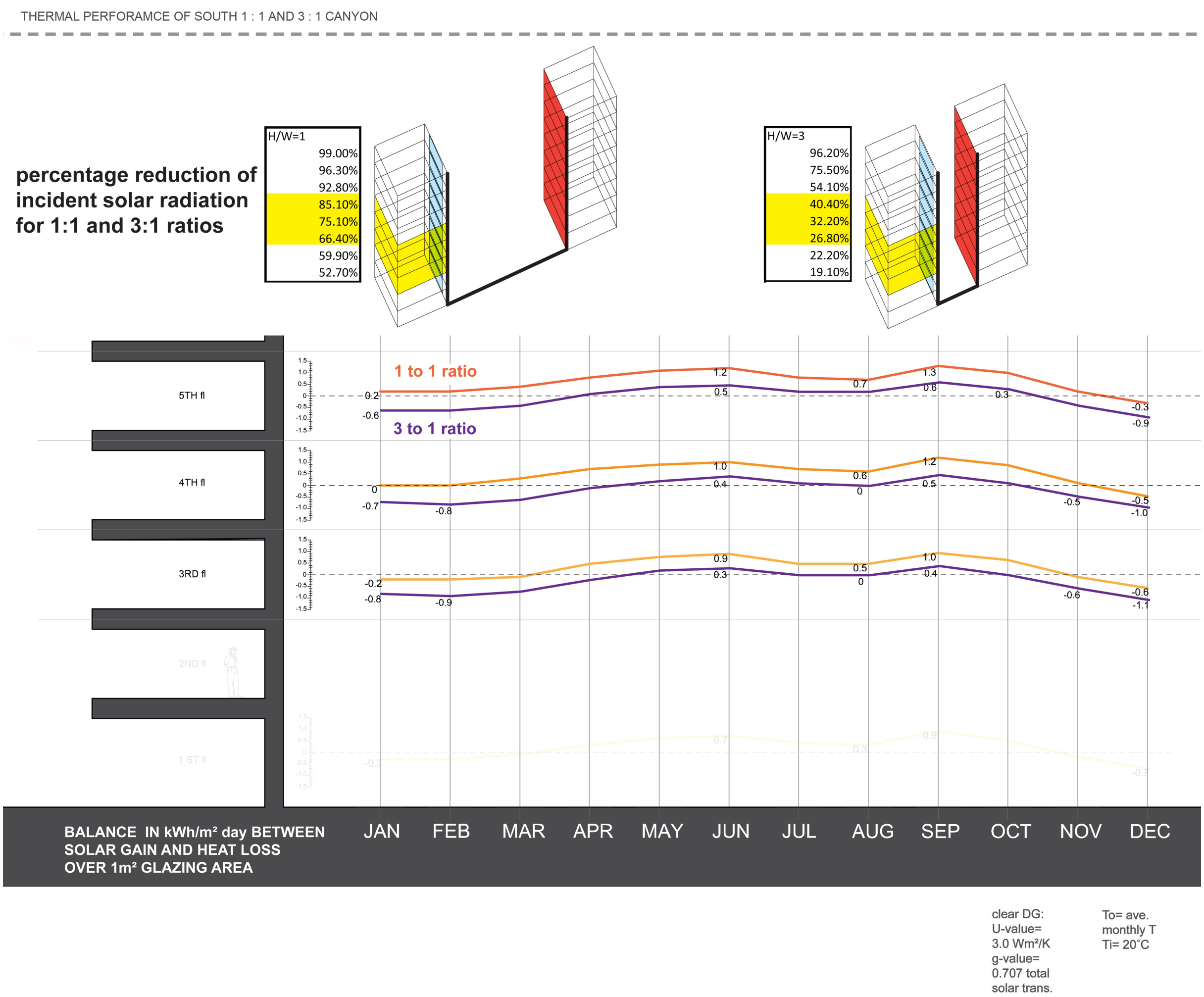

Figure 8 The thermal performance of a 1m² clear double glass glazed area for the two urban canyon ratios-- 1 to 1 and 3 to 1 ratio, maintains a parallel pattern to each other for the entire 12 months.

Three mid floor levels are studied to understand impact of obstruction angles. The balance in kWh/m²day calculates the difference between amount of solar gain and amount of heat loss over the area of a 1m² glazed vertical surface. At the 3 to 1 ratio urban canyon, the percentage reduction of annual incident solar radiation is already less than half of the available amount falling on the south vertical surface of a 1 to 1 ratio canyon. Corresponding to the different percentage reduction in the annual incident solar radiation, the thermal performance of glazing also shows a similar 50% to 60% difference between the two urban canyons. To take a specific example, in Figure 8, the 5th level floor which has a positive balance of solar gain than heat loss until the month of December in the 1 to1 ratio canyon; at the 3 to 1 ratio canyon it shows for almost half of the year, there is greater heat loss than solar gain through the glazed area.

Figure 9 The chart studies the thermal performance of different types of glass. Four types are studied: clear double glazing (U-value: 3.0 Wm²/K, solar transmittance g-value: 0.707), double glazing with low-e (U-value: 1.8 Wm²/K, solar transmittance g-value: 0.616), triple glazing (U-value: 1.2 Wm²/K, solar transmittance g-value: 0.64), and green tinted double glazing (U-value: 2.94 Wm²/K, solar transmittance g-value: 0.422).

The conclusion from this study is that, the three glazing types: clear double glazing, double glazing with low-e, and triple glazing, because of it proximity in solar transmittance g-values, perform similarly in the summer climate of Seoul. But for the cold winter months of November through February, the balance between solar gain and heat loss starts to vary according to their different U-values. In terms of thermal performance for the lowest level floors at the ground, double glazing with low-e appears as a sufficient application for glazing choice to minimize heat loss.

The green tinted double glazing which has been applied to new urban housing construction in Seoul as a substitute or response to higher glazing ratios in the façade performs the worst in the winter season. Due to its lower solar transmittance g-value, the summer performance is stronger than the other options but it is at the cost of an extremely poor winter performance.

CONCLUSION

With an informed building envelope that responds to the climate in Seoul, the performance of the new tower typology is significantly improved. In terms of general strategies for energy saving for the new tower residential typology in Seoul, the most effective measures were found first in replacing the green tinted double glazing(0.422 g-value solar transmittance) with double glazing with low-e. Though the annual cooling consumption increases by 41% with the higher solar transmittance (0.707 g-value) of the double glazing with low-e, the more problematic energy consumption is in heating and this increased cooling amount is reduced again with the application of external shading. The second general strategy is to improve the U-value of the external walls from the standard of 0.47 Wm²/K to 0.28 Wm²/K. The improvement in the U-value of the external wall improves heating consumption by 11%. In addition the application of insulated night shutters and external shading devices to the façade of the new residential tower typology is crucial as an architectural solution in response to the demand for higher glazing ratios. Night shutters with 20mm of insulation with a 0.026 conductivity, can save 30% of heating consumption. The same device which is used as an external shading device can reduce 55.2% of cooling consumption. External shading devices dissipate any absorbed solar energy to the outside air and therefore play a key element for passive cooling. Internal blinds were the least effective in terms of solar control in comparison to external blinds.

To push energy savings to extremely lower values, selective use of the enclosed balcony is necessary in the interior. The final strategy can theoretically achieve values as low as 12.5 kWh/m² for annual heating consumption and 8.1 kWh/m² for annual cooling consumption.

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Establishing Energy Efficient Building Codes in Developing Nations:

An analysis of window characteristics suited to hot-dry climates through a study of the residential byelaws of Lahore, Pakistan.

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ABSTRACT

Evidence that windows are responsible for most heat gain through solar radiation into a building underlines the importance of climatically sensitive window design. Many of the recent building practices in the developing world are dismissive of the more environmentally appropriate traditional building forms, adopting instead, an urban form that is neither environmentally sensitive nor sustainable. Such practices demonstrate a lack of understanding between the thermal performance of windows in relation to the urban geometry, yet are in most instances legitimized by inadequate regional building codes. A case in point is that of Lahore Pakistan, where despite a predominantly hot-dry climate there is no mention of suitable apertures within the building code, this situation is exacerbated in residential areas by the byelaw requiring a mere 1.7m distance between the building unit and boundary wall on two sides of the building. Taking Lahore as a prototypical developing world city, this paper addresses the specific spatial arrangements created through the existing building codes and focuses on controlling solar gains through an analysis of the window characteristics that are most suited to the climatic and urban environment. The discrepancy in building codes is investigated through software simulations that evaluate real housing clusters with particular focus on the obstructed facade (by boundary wall or adjacent building) for which suitable window characteristics that balance seasonal natural light and thermal gains are determined. A further set of simulations addresses the effect of modifications in the byelaws regarding the distance of obstruction and the consequent adjustments necessary to window characteristics. The results of these simulations provide the knowledge-base for a critique of the environmental sensitivity and suitability of the existing byelaws, and propose modifications that would optimize both climatically appropriate window design and land use within the urban environment of Lahore.

INTRODUCTION

The twentieth century technologies and universally available materials have greatly facilitated the trend towards homogeneity of the urban built form across the globe. This trend is popular in all aspects of urban built form but is particularly obvious in the form of public and commercial buildings in most city centers the world over.

Traditional building design was perfected over a long period of time, with the construction practices, architectural vocabulary and urban form of a region being sensitive to the climatic conditions and cultural requirements of that region. The result was an urban-scape unique to the place and the people, with the building envelope maintaining comfortable indoor conditions.

However the influence of new materials and technologies has resulted in a drastic shift in the built form which in most instances is far removed from tradition and also the goal of maintaining comfortable indoor conditions. While these changes to the urban form have been somewhat conscientiously undertaken in First World Countries in that desirable indoor conditions remain within achievable limits, the situation within developing countries, particularly those with hot climatic regions, leaves a lot to be desired. The *modern urban form* in such parts of the world and the accompanying lifestyle is largely reliant on mechanical methods of air conditioning to maintain comfort which is an unsustainable and expensive option. This situation is exacerbated by the unquestioned adoption of design standards that have been developed in colder parts of the world and are geared to satisfying comfort and energy use in developed nations. The extent of this practice can be gauged by the situation in much of South Asia where the comfort standards laid out in ASHRAE guidelines have been incorporated within the national building standards and are legislatively enforced. The irrationality of such practice is reinforced in recognizing that even within regions of the world that are similar in their climatic environment, variations in the comfort parameters will exist due to the differences within the culture and lifestyle choices of the people of the various regions.

The formulation of a robust workable code is rooted in an understanding of the environmental efficiency and behavior of different building types within the particular climatic and cultural environment of that region. Such understanding is typically based upon empirical data, however it appears that not all building types have been given due attention; the urban residential form has been largely ignored in this regard, with the major focus of such research being the traditional building (Oktay, 2002) while the study of modern buildings has remained almost exclusively within the realm of office buildings. It is therefore an imbalanced understanding of thermal comfort and occupant behavior that has been created and on which we continue to base our requirements of comfort.

A robust building code implemented within a well-designed regional energy policy would go a long way toward improving this situation by ensuring the design and construction of all buildings (irrespective of purpose) results in the internal environment being as close to comfort parameters as possible. Comfortable conditions could then be achieved through passive control or low energy measures and if artificial air conditioning were still required, the reduced temperature differential between the desired and existing would result in a significant reduction in energy costs.

In the absence of an accurate database of regionally appropriate comfort parameters the environmental efficiency of the buildings cannot be gauged nor a solid measure of the success of building standards formulated. At the very least, existing inappropriate guidelines can be modified in order to adapt them to the local climatic conditions. Focusing on the hot-dry South Asian scenario, the primary *design flaws* in the existing standards that render it inapplicable are:

The glazing ratio: The design guidelines for window size and placement were developed in climates that design for daylight: providing adequate natural light in to the building. These recommendations were based on the window area to wall area of the room and vary for different climatic zones; the consensus however is that the optimal glazing ratios lies between 25% and 40% providing adequate light while not incurring undesirable thermal gains and avoiding disability or discomfort glare (Muneer et al, 2000, Baker et al, 2000). In a hot climate, however, there is ample sunlight and providing natural light into the building is not of concern. Rather, the glazed surface area needs to be managed in order to control the solar gains in the building.

Rate of air change: Traditionally based on standards developed for maintaining desirable internal conditions in a conditioned environment, the rate of air change is not applicable to naturally ventilated buildings in hot climates where the speed of air takes precedence over rate of air exchange purely for the cooling effect of air movement.

The following addendum to the standard requirement of air changes is seen as:

Wind speed: The cooling effect of wind speeds between 0.5m/s and 3m/s has been documented however speeds above 1.5m/s are not advised because of the nuisance factor created through the disturbance of paper etc. (Baker, 2000). The cooling effect of re-circulated air through the use of mechanical fans is utilised in most hot climatic regions the world over. This reliance on fan generated wind speed to counteract the effect of increased temperature has been documented to ‘occurs [sic] at temperatures of around 26^{o}C’ (Nicol et al, 2014 p.128). The consequent reduced temperature is known as the *Effective Temperature*. The cooling effect produced is significant with a wind speed of 1m/s causing a 3^{o}C reduction in effective temperature at 30^{o}C (Baker, 2000), and 4^{o}C at 40^{o}C (Nicol, 1994).

It is surmised that recirculation of indoor air in hot climates would prove a beneficial low energy measure and should be accommodated within building standards and guidelines particularly in such regions where such practice is established.

Thermal Comfort in a hot-dry environmnet

The rigidity of comfort parameters determined through climate chamber experiments does not reflect the seasonal variations within conventional comfort ranges wherein occupants adapt to the environment and accept significant deviations in their surroundings. This behavior has been utilized in the development of the adaptive model for achieving comfort and recently this approach has been validated by several international standards such as ASHRAE 55-2004 and EN15251 through the recognition that indoor comfort temperatures are dependent on changing outdoor conditions (Nicol et al, 2014).

One such representation of the relationship between indoor comfort temperature and outdoor temperature is the 1978 formula developed by Humphreys:

$$T_c = 12.1 + 0.53T_o \qquad (1)$$

Where T_c is indoor comfort temperature and T_o is outdoor temperature.

This formula has been found to be 95% accurate in predicting comfort temperatures during summer months for occupants in environmentally controlled buildings in the South Asian country of Pakistan (Nicol et al, 1995). It is assumed that the range of validity of this formula will have an upper limit of 47^{o}C, (the average high temperature of Multan, one of the 5 cities in the study and with the highest average temperatures of the sampled cities).

It is to be noted that this equation does not take into consideration the cooling effect of wind speed. The use of ceiling fans is standard adaptive behaviour in such climatic conditions and the Oxford Brookes report specifically mentions the cooling effect of ‘about 2^{o}C for average air movement’ in Multan with ‘an approx 4^{o}C shift between still air and 1m/s’ (Nicol, 1994, p23). A modification of Humphreys’ formula is thus undertaken to incorporate a conservative 2^{o}C reduction in temperature due to the effect of re-circulated air movement, giving the relationship for *Effective Comfort Temperature* ($T_{ce.}$):

$$T_{ce} = 10.1 + 0.53T_o \qquad (2)$$

LAHORE, A CASE IN POINT

The case study undertaken is the city of Lahore in Pakistan, a typical developing world city which is prone to the issues of conformity to developed world trends in urban form and lifestyle. Located at 31.34^{o}N and 71.20^{o}E, Lahore experiences severe hot-dry summer with a mean average temperature of over 35^{o}C for five months of the year and remaining over 30^{o}C for a further two months (Weatherspark, 2013). With peak summer temperatures of over 45^{o}C, the control of solar gain was the central design consideration in indigenous architecture. The modern urban form however has abandoned the dictates of tradition, with thinner walls (standard construction of 9” load-bearing brick masonry), lower thinner flat roofs, and significantly larger glazed apertures – where previously apertures were small and were protected from the sun’s glare by either external open-able shutters or fixed marble/wood jalli.

The situation in Lahore epitomises the unsustainable condition of the urban-scape of many parts of the developing world with the existing energy regulations based on inadequate research and the local building codes largely ignoring the issue of thermal performance of residential structures. Lahore falls within the same climatic region as Multan, and as such the predictive values of Equations 1 and 2 in the preceding section are applicable. In Lahore where the mean maximum summer temperature is 40.4^{o}C, indoor comfortable conditions would be at 33.7°C, or at 35.7°C where the environment is supplemented with fan-generated re-circulated air.

The Building Code

Much of the residential development within the city falls under the jurisdiction of two major and several minor building control agencies all of which conform to national recommendations. Through this, residential structures within Lahore are regulated within the same byelaws and guidelines irrespective of their location. Universally the building codes specify mandatory clear areas on the periphery of plots –the depth of which is dependent on the dimensions of the plot, residential units are restricted to two storeys in height with a maximum height of 8m and with the upper storey limited to 75% of the floor area of the ground.

The cultural trend, supported by the high land prices is to construct over the entire area permitted by the building codes. This trend combined with the uniformity of plot sizes, a rectilinear *industry standard* road network, and building code dictated volumetric conformity produces a high density low-rise urban form which has remarkable similarity with respect to open spaces between buildings and solar shading by adjacent buildings.

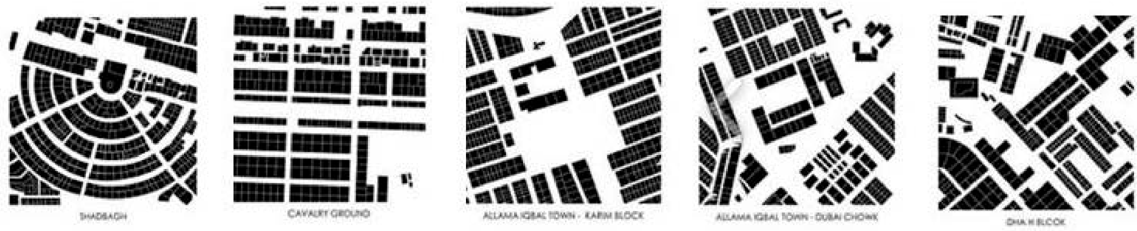

Figure 1 Nolli plans of a sample of residential colonies in Lahore. Density of form and compact nature of planning is clearly visible. (OCCO, 2009)

The primary focus of this study is the largest development authority of Pakistan, The Defence Housing Authority (DHA) within which the development typifies the urban geometry of the city both in density and building form. An initial survey of the sample residential units within the DHA confirmed the translation of the building guidelines is taken literally: in most instances the minimal distance required towards the sides (and the rear of all but the largest plot size) of the residential unit, a mere *passageway* of 1.7m (including boundary wall width) is maintained. Further to this, as the bye-laws limit the height of the boundary wall to 2.13 metres, the facades on at least two sides of all residential units are affected by an obstruction in the form of the boundary wall and close proximity of the neighbouring building.

Table 1. Existing Byelaws for Residential Plots, DHA, Lahore Pakistan (DHA, 2002)

Area (m^2)	Area (sq.yd)	Dimensions (m)	Front (m)	Rear (m)	Side (m)	Side (m)
836	1000	22.86x36.58	6.32	2.55	1.7	1.7
836	1000	30.48x27.43	6.32	2.55	1.7	1.7
418.3	500	15.24x27.43	4.8	1.7	1.7	1.7
211.27	250	10.67x19.80	3.28	1.7	1.7	1.7
104.55	125	7.62x13.72	1.52	1.7	1.7	-

METHODOLOGY: ANALYSIS OF THE EXISTING BUILDING

The current building codes in Lahore have not been designed with a view to develop an environmentally sensitive and sustainable urban form. However an analysis of the buildings created through conformation to the building code will determine a base line of environmental suitability of the code. In order to determine the primary source of uncomfortable indoor conditions, the dissection of the urban form into its basic parts: the building and the urban geometry formed of neighbouring buildings is undertaken.

A random selection of existing residential buildings within the DHA area – providing at least 5 from each plot type, yielded a set of building plans that were then analysed, the significantly atypical disregarded and from the remaining sample pool, a ‘typical’ residential unit selected.

Preference was given to the 500 sq.yd. (418.3m^2) buildings as these are representative of approximately 70% of the residential building size in DHA. Furthermore the byelaws applied to this plot size require the minimum distances of 1.7m from the boundary wall on three sides resulting in greater applicability of any analysis.

Figure 2 (a) Building footprint of randomly selected existing residential buildings within DHA limits. Prototypical residential unit used for modelling purposes highlighted. (b) 3D model and floor plans of selected residential building.

The typical residential unit selected above is simulated with the EDSL’s (Environmental Design Solutions Ltd) software Thermo Analysis Simulation (TAS). For the purpose of this analysis, the building is modelled in peak summer conditions for one day (day 180/360) with the number of preconditioned days set to 15 (this equates to the building experiencing the environment for 15 days and analysed on day 16, providing a realistic representation of the environmental sensitivity of typical buildings). The building is simulated as unoccupied and without internal gains so as to provide an unadulterated measure of the effect of the outdoor environmental conditions. The internal partitions are taken to be unopened. The building envelope is true to popular construction materials and the apertures are single-glazed with a U-value of 5.7 which reflects occupant preferences based on empirical sales figures: 65% of occupants opt for single-glazed while 35% opt for double glazed. The primary focus of the study is the ground floor level of the building so as to minimise the effect of thermal gains through the roof.

The contribution of the urban geometry:

The typical residential building was modelled under various exogenous influences that together make up the urban geometry of the area. The building was simulated with each parameter in isolation and also incrementally to determine the effect of the urban geometry as a whole, thereby determining which areas need addressing with regard to environmental sensitivity.

These parameters are: the influence of the boundary wall at 1.7m, the neighbouring residence at 3.4m, and the overall effect of the urban-scape (a residential block of 6 houses, with the central one analysed). These simulations showed an expected increase in the internal temperature of the building unit due the introduction of the boundary wall, however there was no significant change to the internal conditions due to changes in distance of wall from the building edge. Furthermore it was found the close proximity of the neighbouring residence had a positive effect on the indoor climate possibly through the shading factor of building. Overall it has been determined that the effect of the urban micro-climate is an increase in the indoor temperature of the residence, by a maximum of 0.6°C.

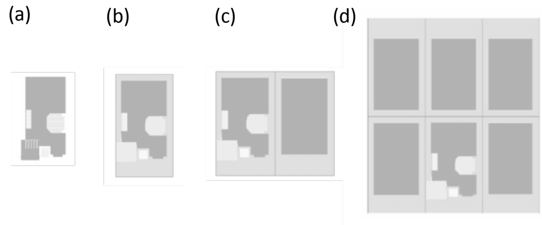

Figure 3 Representative plans of the typical residential building as simulated: (a) building in isolation, (b) with 2.13m high boundary wall at 1.7m, (c) with boundary wall and adjacent building at 3.4m., (d) within a typical block of residential units.

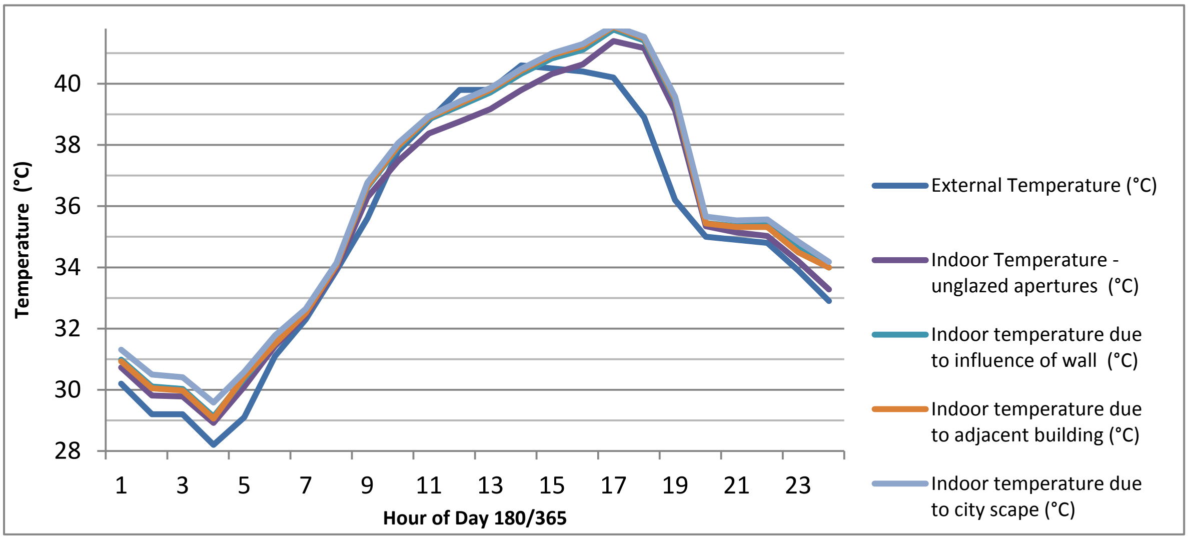

Figure 4 Simulated temperature for 24 hour period over day 180/365 (30th June). Unglazed apertures. Comparison of effect of urban-scape on the indoor temperature.

The environmental sensitivity of the building envelope:

Two preliminary simulations were undertaken for the purpose of developing a baseline for comparison. The first with all apertures opened for 24 hours, with the building unit as an unglazed shell, this simulation showed no significant difference between indoor and outdoor temperatures. The second with the glazed apertures closed for 24 hours where an increase in indoor temperatures by over 3°C signifies the negative effect of the glazed apertures within the building envelope.

In an attempt to mimic typical user behaviour of closing out the harsh intense heat of the day and opening up and airing the inside of the residence during the cooler night, a series of simulations were carried out where the apertures were opened for a few hours of the day. The simulations indicated opening the windows for a period of 12 hours, from 1900 Hrs to 0700 Hrs yields the most significant reduction in internal conditions with the highest indoor temperature (west facing areas) becoming 3.4°C lower than the outside There is however a time-lag between maximum indoor and outdoor temperature of 4 hours (see Figure 5).

The detrimental effect of glazed apertures on the indoor temperature (3°C) is significantly higher than the increase due to the effect of the urban micro-climate (0.6°C) hence further investigation is directed towards the building envelope. For the purpose of assessing the worst case scenario, all further simulations concentrated on the regions of the building most affected by solar gains: the west facing areas. The treatment of the apertures was scheduled as opened for 12 hours: 1900 to 0700.

Overcoming inappropriate glazing:

A simulation was conducted to compare the suitability of double glazed with single glazed apertures in a hot-dry climate. It was determined that double glazed apertures are climatically appropriate as they maintained an indoor temperature 0.5°C lower than single glazed apertures.

A series of simulations were carried out where the building was augmented with various shading devices. These included a 1m deep shade, 2.5m shade, and a 2.5m deep veranda (with walls enclosing the veranda space). A comparison of the effect of such shading devices led to the conclusion that while temporary respite may be achieved from direct sunlight and associated glare discomfort, the change to internal temperature within the building is negligible.

A comparison of the simulations undertaken indicate a reduction of the window area by 50% (to 15% glazing ratio) leads to an improvement of the indoor environment by over 2°C bringing the (maximum) indoor temperature down to 34.8°C –which is an acceptable indoor comfort temperature. The smaller window size results in a slower decrease in indoor temperature at night with the temperature remaining 2.5°C higher than outside temperatures (see Figure 5).

Augmenting passive control: Forced Ventilation

The passive control of the indoor environment is augmented with a degree of mechanical control through forced ventilation. The introduction of cool outside air into the indoor environment results in a reduction in temperature, however the intrusion of dust and insects necessitates control over the quality of air used for ventilation. A solution to this issue is in the form of forced ventilation whereby outside air may be filtered and forced into the indoor environment. This is a variation of the standard supply system of forced ventilation where outside air is brought in and creates a positive pressure (Szokolay, 2008).

The building is simulated to follow the schedule of apertures open during the evening hours from 1900Hrs to 0700Hrs and adjustments are made for an increased air change rate (as a means of controlling air velocity) during the same schedule to mimic the inclusion of forced outside air. Assuming the outside air speed to be 1m/s (the average air speed in Lahore is approximately 4.5m/s for July) (Weatherspark, 2013) the number of air changes through a $2m^2$ window (at 15% glazing ratio) and a room of $77m^3$, as simulated, is at 97. A conservatively applied air change per hour value of 50 results in a reduction to the internal temperature by 0.5°C.

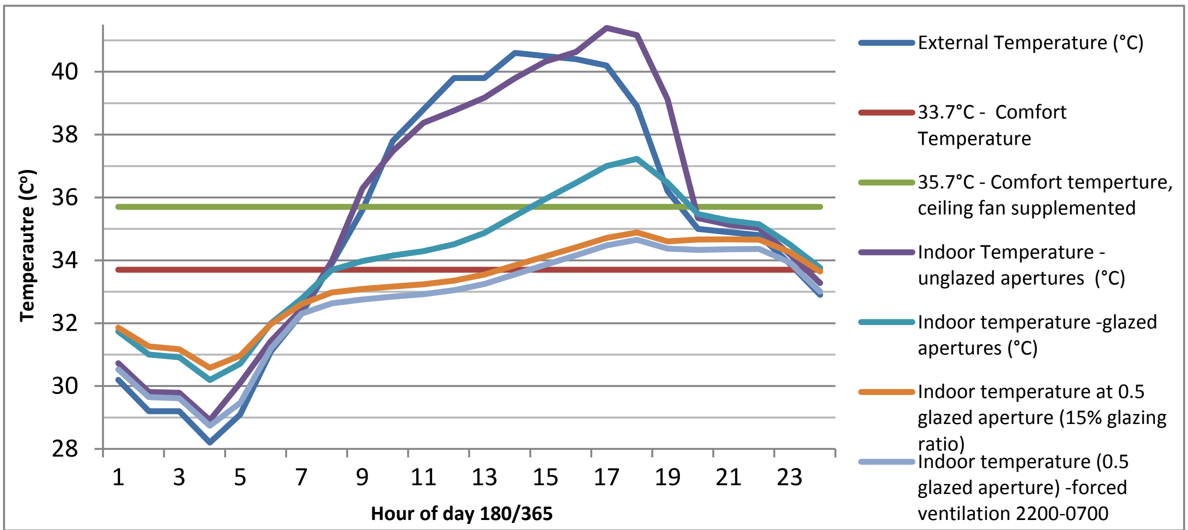

Figure 5 Simulated temperature for 24 hour period over day 180/365 (30th June). Comparison of change in temperature due to change in glazing ratio and with forced ventilation.

A slight modification to the schedule postpones the start of forced ventilation till 2200 Hrs when the outside air temperature has dropped to below 35^{o} with the result of the indoor temperature remaining between the comfortable values of 34.5^{o}C and 28.8^{o}C.

The 1st floor:

The difference between the indoor temperatures of ground floor and a similar space at the 1st floor region is an average of 1.1^{o}C which with the introduction of the passive and mechanical control measures listed above comes down to 0.5^{o}C. The result is a significant reduction in indoor temperatures for both floors and further reductions can be attempted by focusing on the insulating properties of the roof construction.

CONCLUSIONS

This paper has attempted to assess the role of building codes in establishing thermal comfort within the indoor environment. Focusing on hot-dry climates and taking Lahore Pakistan as a case study some shortcomings in the building code are identified, foremost of which is the absence of locally relevant thermal comfort parameters.

Taking the urban geometry and the building envelope as products of the building code, specific contributions of the indoor environment of a typical residential structure were studied through software simulations. The simulations indicated that the urban geometry has both a positive and negative effect on the indoor environment; the effect of the urban micro-climate being an increase in temperature while the close proximity of neighbouring buildings dampening this rise possibly due to their shading effect. The simulations further indicated that the building envelope is responsible for most of the heat gain to the interior of a building and that the primary contributor to uncomfortable indoor conditions are the glazed apertures within the building envelope. It was also determined that through a simple reduction to glazed surface area, augmented with low energy mechanical conditioning (such as ceiling fans and forced night-time ventilation) the indoor environment can be brought to within comfort levels.

The overall focus of the work has been upon the achievement of thermal comfort through the use of passive and low energy measures. The work indicates this is an achievable target for a sizeable section of the population, it thus contributes towards laying the ground work for modifications in building codes to achieve this objective.

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Impact of Vegetation in Urban Open Spaces in Dhaka City; In Terms of Air Temperature

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ABSTRACT

Dhaka is a highly vibrant megacity with almost 15 million populations (World Bank, 2013). Due to high density in an undisciplined urban setup, the city is in real scarcity of open and green spaces for her large number of dwellers. The rapid growing population in conjunction with very immediate developing urbanization has led to unplanned and uncontrolled expansion of Dhaka which is resulted in the gradual loss of open and green spaces in the city. In the quest of meeting the great demand of urbanization, the city has hardly saved some of her natural spaces. Unfortunately these very few existing open spaces are not even well preserved with natural greeneries or vegetation; as a result this lack of green and plantation severely affects the microclimate of those spaces. Whereas the use of vegetation and plantation as an element of urban landscape, has always great environmental benefits and opportunities both in the scale of micro and global climate; like temperature control, solar radiation control, wind control, reduction of air pollution by absorption the pollutant and noise reduction etc. Urban vegetation minimizes direct solar radiation of the surface, optimizes wind velocity and its form and configuration influence temperature, air humidity and wind pattern of an urban setting. Vegetation create green barrier as visual boundary, natural screen and space buffer as a major element of landscape design.

The objective of this paper is to discuss the impact of vegetation in urban air temperature and explore the possibility of vegetation configuration to maximize the cooling effect in urban open space in Dhaka city. For researching these issues, a short field survey has done in two significant urban squares to find out the answer of the proposed research query. An evidence based microclimatic simulation software ENVI-met is also used to compare the outcome data of the field survey.

INTRODUCTION

Preface

The rapid growing population in conjunction with very immediate developing urbanization has led to unplanned and uncontrolled expansion of Dhaka which is resulted in the gradual loss of open and green spaces in the city. In the quest of meeting the great demand of urbanization, the city has been developing her infrastructure as well as built environment by continuous ignorance of nature which has hardly saved some of her natural spaces. Comparing with rural surroundings, this built environment of Dhaka city is mostly uncomfortable to her dwellers' experience. Expansion of unplanned urbanization and built structure results cutting a large number of trees and converts the green areas in concrete surfaces. A minimum 25% of forest cover is suggested for a healthy living (Mowla, 1984) where at present in old Dhaka (old part of the city) only 5% and new Dhaka (new part of the city) 12% of land is

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green and open (Mowla, 2011). Green spaces with vegetation have great environmental benefits and opportunities. Vegetation has potential to reduce environmental temperature. Its form and configuration influence solar radiation, temperature, air humidity and wind flow of an urban setting. This paper states the impact of vegetation in urban air temperature and explores the possibility of vegetation configuration to maximize the cooling effect in urban open space in Dhaka city.

Statement of Problem

Use of excessive exposed hard surfaces like brick and concrete pavements and plaza, pitched road, buildings, air-conditioning system etc are responsible for raising urban air temperature. The urban spaces of a city are considered more vibrant when it can allow more people for outdoor activities. So it is important to create attractive and welcoming open spaces for the public, where outdoor comfort can be an important criterion. Again, air temperature is a vital aspect for this outdoor comfort. It is found that when meteorological data of average air temperature for Dhaka is 28 C (23 Feb, 2012) then the average air temperature of the paved area of Shahid Minar is 32 C (Field Study). Vegetation is an important element of nature. Being an organic element, vegetation has some impact on local microclimate as well as global climate. That is why this study is focused on the impact of vegetation in urban open spaces in Dhaka, in terms of air temperature.

Objective

The objective of this study is:

- To determine the impact of vegetation in open spaces in Dhaka city in terms of Air temperature.
- To find out the possibility of vegetation configuration to maximize the cooling effect in urban open space in Dhaka city.

Methodology

The methodology of this study can be described in three steps and these are:

Step 1: Literature Review and Theoretical Basis: Study the relationship between vegetation and basic four environmental components and the impact of vegetation on the open spaces from different paper, journal, books, articles etc.

Step 2: Field Study: A short field survey (in two urban open spaces) has been done in the current situation of Dhaka. This part is very important for this research because this research is based on field study and the output provides the current microclimatic data of the study area. Two urban spaces of similar context are taken for this study. The "Shahid Minar Chattar" (approximate area 120000 sft), located in the Dhaka University area and the "Pantha Kunja" square (approximate area 260000 sft), located beside the city commercial zone, Karwan Bazar node, Dhaka. Both spaces are laid in north-south direction and consist of both paved and green area. This step will find out the answer of the query, whether is there any variation of air temperature happened for presence of green vegetation and urban pave?

For data collection, 6 Points (spot) have been taken (in almost equal distance) on an imaginary line along the centre (north-south direction) for the both cases for measure the air Temperature, Humidity and Air Velocity. Here for Shahid Minar Chattar, lump sum 500 ft distance has being taken, where after every 100 ft one data point has located in the case study 1**(Figure 6 a)** and for Pantha Kunja, lump sum 1000 ft distance is being taken, where after every 200 ft in park area and every 100 ft in paved area, one data point has located in the case study 2 **(Figure 7 a)**. All data (18 set) have been taken on that imaginary line above 1m ground level with the Kestrel 3000 Pocket Weather Meter. The data was being taken on February, 2012 on morning 10.00 am, noon 1.00 pm and evening 4.00 pm.

Step 3: Simulation: Microclimatic simulation has been done by ENVI-met software to compare with the survey results. The full areas (draw in **Figure 6a & 7a**) of the two urban spaces are considered for ENVI-met modeling. Input data are found from field survey and weather data of Dhaka.

Limitations

A number of limitations have observed in this study, like time, resource and some practical problems. The survey for this study is held in the month of February where June to September are the hottest (considering highest temperature database) months for Bangladesh. During the survey it was very difficult to locate accurate point for measurement. Sometimes it was difficult for the users and different activities on the spots.

LITERATURE REVIEW

For this paper, urban space means that the space which is designed or created and used for deferent public activities in Dhaka and vegetation means the plants of an area or a region. Vegetations can be classified in different categories. In broader classification: Herb, Shrub and Tree. Herbs are seed-bearing plant whose aerial parts do not persist above ground at the end of the growing season where as Shrub is a woody perennial plant, smaller than a tree. Trees are any large woody perennial plant with a distinct trunk giving rise to branches or leaves at some distance from the ground. Again In terms of density, according to John P. Caouette and Eugene J. DeGayner, they are two types, Low (SDI < 280) and High (SDI > 280) (Caouette and DeGayner, 2008). Stand density index (also known as Reineke's Stand Density Index after its founder) is a measure of the stocking of a stand of trees based on the number of trees per unit area and diameter at breast height of the tree of average basal area.

Now the relationship of vegetation and four major components of the climatic features of environment, Solar Radiation, Air Temperature, Humidity and Air Flow discuses bellow.

There is close relationship between vegetation and solar radiation. According to Wardoyo (2011), individual leaves of the vegetation allow, some radiation to be transmitted through them (20%), absorb some radiation (55%), and reflect some radiation (25%). The leaf absorbed the solar radiation and re-transmitted it by evapotranspiration which increases relative humidity and reduces air temperature (Wardoyo, 2011). Large trees with spreading canopy can also provide shade and protect surface from direct radiation. Bueno-Bartholomei and Labaki found that, the structure of the crown, dimension, shape and colour of vegetation leaves influence reduction level of solar radiation (Bueno-Bartholomei and Labaki, 2005).

Vegetation in open space has low reflectance value that helps to reduce the air temperature in an urban surrounding. Vegetation does not radiate the long wave radiation which helps to maintain lower air temperature. Evapotranspiration reduces air temperature and increases relative humidity (Wardoyo, 2011). Tree shade also helps to reduce the air temperature. Zahoor (1997) in Pakistan found that vegetation has significant influenced to local temperature and effective in reducing air temperature about 6 –7 °F.

Again, according to Wardoyo (2011), vegetations also influenced the pattern of air movement through guidance, filtration, obstruction and deflection. Air movement sometimes depends on vegetation characteristic and configuration. Scudo (2002) establish that geometry, height, permeability and crown of the vegetation are the structural vegetal characteristic that influenced the controlling air movement.

Evapotranspiration reduces air temperature that increases relative humidity. It is found that relative humidity is always higher in the green areas.

Again the environmental criteria in Dhaka City are also important for this study. Bangladesh is in Warm Humid Tropics. Generally she has six seasons according to natural, cultural and social activities. But climatically, the climate of Bangladesh can be divided into four seasons. According to Hossain and Nooruddin meteorologically the climate of Bangladesh is categorized into four distinct seasons Winter (cool dry), Pre-Monsoon (hot dry), Monsoon (hot and wet), Post-Monsoon (hot and wet), where Winter months (December to February) temperature 21-26 C, Pre-Monsoon (March to May) temperature max 34 C, Monsoon (June to September) avg. 31 C, Post-Monsoon (October to November) temperature bellow 30 C (Ahmed, 1996). Average Relative Humidity is 60-80%. Radiation on a horizontal surface 5.00 kWh/ m2 and Air Flow 4.1 m/s (Ahmed, 1996).

The simulation tool, ENVI-met is a three dimensional microclimate model designed to simulate the surface, plant, air interactions in urban environment with a typical resolution of 0.5 to 10 m in space and 10 sec in time. Typical areas of application are Urban Climatology, Architecture, Building Design or Environmental Planning, just to name a few. ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. (ENVI-met web)

TYPES OF VEGETATION AND CLIMATE COMPONENTS

Table 1. Impact of Vegetation and Climate Components

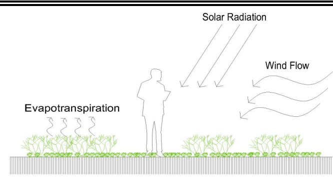
<table>
<tr><th colspan="2">Classify plants</th><th>Solar Radiation, Air Temperature, Air Flow and Relative Humidity</th><th>Comments</th></tr>
<tr><td rowspan="3">In General</td><td>Herb</td><td>

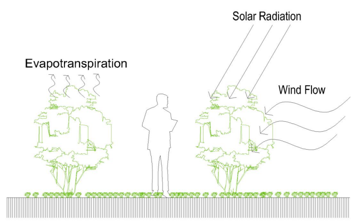
Figure 1: Impact of Herbs</td><td>_ Direct solar radiation and Air temperature is higher than other cases in open spaces.
_ Uninterrupted wind flow.
_ Relative humidity depends on density of green.
_ Reduces dust and no visual barrier.</td></tr>
<tr><td>Shrub</td><td>

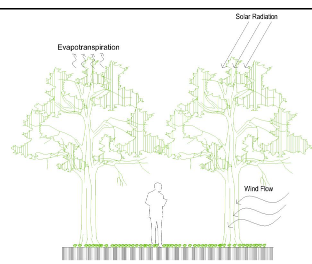
Figure 2: Impact of Shrubs</td><td>_ Sometimes small shaded area or sometimes direct solar radiation in open spaces.
_ Shrubs hinder the natural wind flow in human level, but a large or smaller shrub allows air flow in human level.
_ Relative humidity is high in human level.
_ Sometimes filters air and create barrier.
_ Flowering shrubs are good in terms of aesthetics.</td></tr>
<tr><td>Tree</td><td>

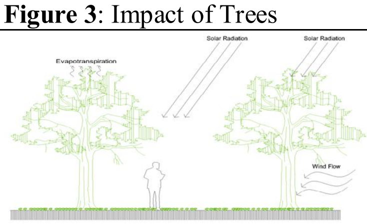
Figure 3: Impact of Trees</td><td>_ Create shaded spaces.
_ Allows gentle wind movements in human level, and filters or guiding the movements in.
_ Sometimes ground cover do not grow in the soil because of large shading tree and lack of solar radiation.
_ Air temperature is less in the shading area.
_ Relative humidity is high under the tree.</td></tr>
<tr><td rowspan="2">Density</td><td>Low (SDI < 280)</td><td>

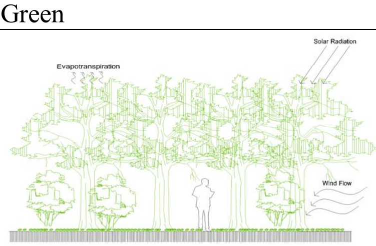
Figure 4: Impact of Low Density Green</td><td>_ Allows direct solar radiation.
_ Allows gentle wind flow.
_ Air temperature is less than a paved area.
_ Relative humidity is moderate.
_ Allows ground cover in the soil.</td></tr>
<tr><td>High (SDI >280)</td><td>

Figure 5: Impact of High Density Green</td><td>_ Do not allow direct solar radiation.
_ Hinder wind velocity sometimes allows tunnel effect.
_ Air temperature is less than other situation
_ Relative humidity is high.
_ Sometimes do not allow good grass on ground and Create dark shade.</td></tr>
</table>

FIELD STUDY

Case Study 1: Shahid Minar Chattar

"Shahid Minar Chattar" is a historically and culturally significant place for Dhaka city. This monument carries the memories of our language movements on 1952. This public space is a large hard paved area with small green and large trees. Green area is surrounded the main monument area. A number of paved stairs leading to the upper platform of the monument is an important public plaza for socio-cultural activities. There is no large structure along the monument. This area is completely exposed to the sun. 6 points are being taken for data collection, which are as follows. (**Figure 6**)

Point 01: Located in a Green space (soil) with tree shade behind the main monument.

Point 02: Located in Red Brick pave with no shade and no green. Higher than ground level.

Point 03: Located in Large Red Brick pave with no shade and no green.

Point 04: Located in a Green space (soil) with tree shade. There is pave around this area.

Point 05: Located in a Green space (soil) with tree shade. But beside the road pave.

Point 06: Located in the road pave.

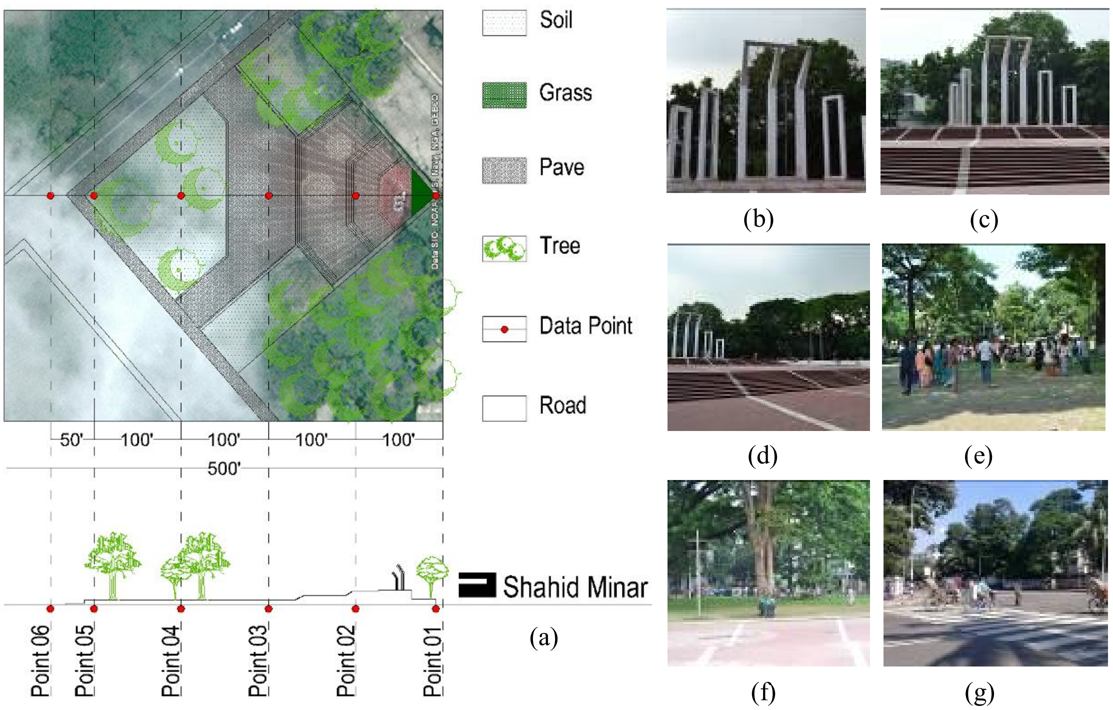


Figure 6 (a) Top view and section of Shahid Minar (b) Point 01 (c) Point 02 (d) Point 03 (e) Point 04 (f) Point 05 (g) Point 06

Case Study 2: Pantha Kunja Square

Pantha Kunja is the only open space cum green space in Karwan Bazar area, one of the important commercial hubs of Dhaka city. It has two parts: one is Green Park with large trees and limited pave area and another consists of large pave with small green area (herbs and shrubs). This area is also completely exposed to the sun. 6 points are being taken for data collection, which are as follows. (**Figure 7**)

Point 01: Located in a Green space (grass) with tree shade with little pave.

Point 02: Located in a Green space (grass).

Point 03: Located in a Green space (grass) with tree shade.

Point 04: Located in Large Yellow and Red Brick pave with no shade.

Point 05: Located in Large Yellow and Red Brick pave with no shade beside small green.

Point 06: Located in the footpath pave beside the road.

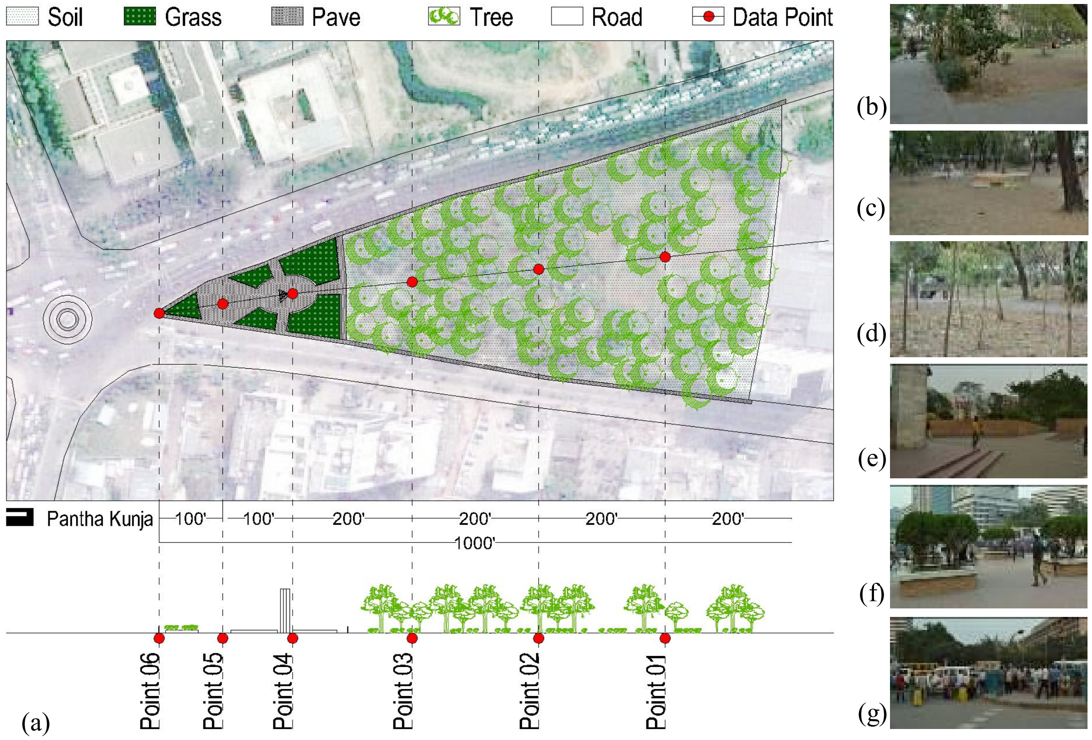


Figure 7 (a) Top view and section of Pantha Kunja Square (b) Point 01 (c) Point 02 (d) Point 03 (e) Point 04 (f) Point 05 (g) Point 06

Results and Findings from Field Survey and Software Simulation

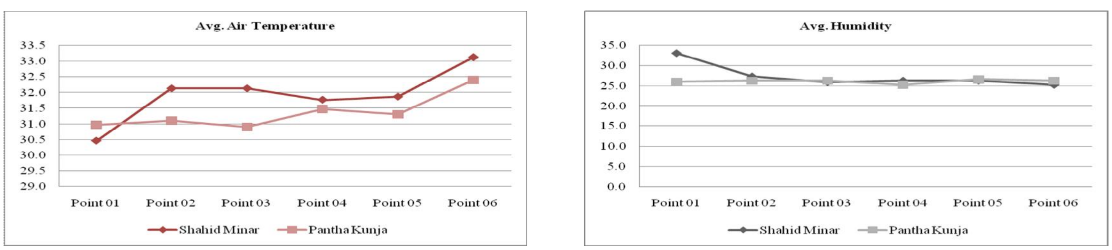


Figure 8 (a) Average Air Temperature Diagram (b) Average Relative Humidity Diagram

ENVI-met Simulation

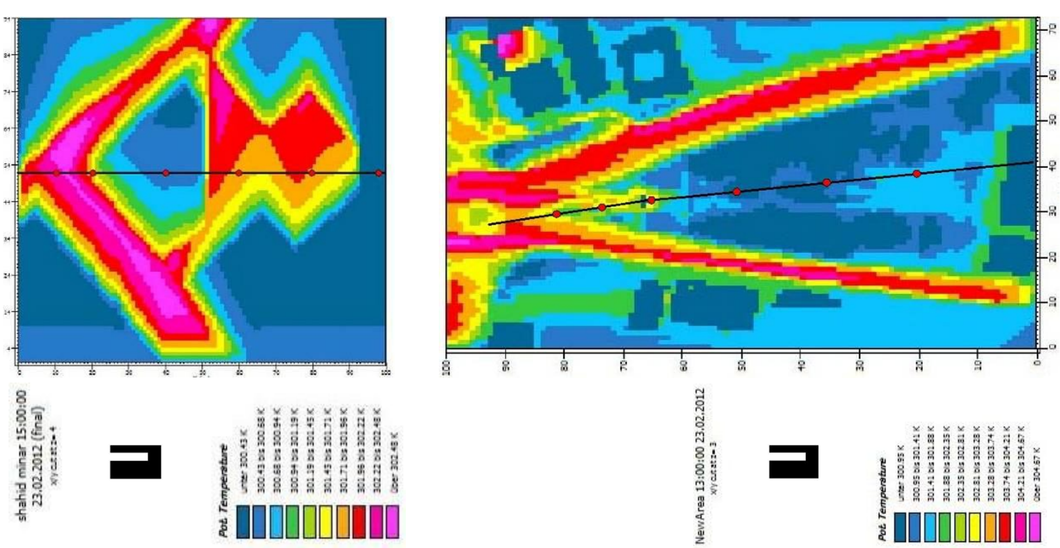


Figure 9 (a) Thermal Image of Shahid Minar Chattar (b) Thermal Image of Pantha Kunja Square

Here are the charts of average value of Air Temperature and Relative Humidity which are being found from field data **(Figure 8)**. For ensuring human comfort in any urban context, relative humidity is equivalently relevant and important with temperature. That is why, in field survey, Relative humidity has always taken in consideration for analytical observation.

VEGETATION AND OPEN SPACE CONFIGURATION

It is found from Case study 01 and Case study 02 that air temperature in a green space is remarkably less than a paved or built space in Dhaka city. In Case Study 01, Average Air Temperature in green area varies from 30.5 C to 31.8 C where in paved area varies from 32.1 C to 33.1 C. In Case Study 02, Average Air Temperature in green area varies from 30.9 C to 31.3 C where in paved area varies from 31.5 C to 32.4 C. Here some other issues can be considered as follows.

Orientation: An imaginary line is taken through Case Study 01 considering north south direction. In our country the wind flows from south east direction in summer. So point 01 is 30.1 C which is less than point 04 and point 05 (31.8 C and 31.9 C) for the wind flow through the plaza area from south. Again an imaginary line is taken through Case Study 02 in same north south direction. In this case the large green is in the south part of the square which create cool environment in pave area on north.

Shade: The shaded area of green space is much cooler than the exposed area. Shade can provide by large trees or other minimal built objects. In Shahid Minar point 01 is always shaded by large dense trees. So the air temperature in point 01 is always cooler than other green spaces. In Pantha Kunja point 02 is exposed to the sun. As a result air temperature in point 02 is higher than point 01 and 03.

Types of vegetation: It is also an important issue. In Shahid Minar, there are small numbers of trees founded in selected green area. There are a few grasses found during this survey. There is no herb, shrubs and trees in the paved area. In Pantha Kunja, there are herbs, shrubs and trees founded in the park area with grasses on ground which helps to reduce the air temperature as per survey data. In the pave area there is also small green area founded with herbs which might helps to reduce the air temperature.

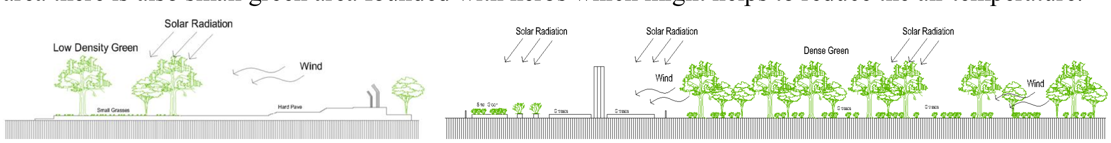


Figure 10 (a) Section of Case Study 1, Shahid Minar; (b) Section of Case Study 2, Pantha Kunja Square

Vegetation Density: Vegetation density also effects the cooling. More dense vegetations increase Evapotranspiration, which reduces the air temperature. Pantha Kunja green area is denser than the Shahid Minar green area and it is also a cause of less average temperature in Pantha Kunja.

Area of the Vegetation: In Shahid Minar almost 80,000 sq ft green area and 40,000 sq ft in pave area where as in Pantha Kunja 240,000 sq ft green area and 20,000 sq ft pave area. Average temperature in Pantha Kunja is less than the Shahid Minar area (survey). Larger area of vegetation contributes in better cooling effect.

Surrounding Vegetation and Presence of Built Objects: Surrounding area has also an impact in the air temperature. Here surrounding area is not considered enough. For Shahid Minar, if a 500 ft diameter circle is considered, more green area with few built area are found which has a cooling impact on local air temperature. In Pantha Kunja if a 1000 ft Diameter circle is considered, more exposed pave and glaze area with more built structure are found.

Vegetation and Relative Humidity: Relative Humidity is much related component to air temperature. As per graph **(Figure 8(a) & 8(b))** air temperature and humidity varies in vice versa. Temperature rise is responsible for reducing the relative humidity. In this study the relative humidity data has also taken for observation.

OBSERVATION

Vegetation has tremendous impact on local microclimate. From the observation of this study some points can be illustrated as follows:

- Presence of vegetation minimizes direct solar radiation and reduces microclimatic air temperature (3C - 4C) in an urban space.
- As wind flows from south east in Bangladesh (generally), vegetation locating in south can help to reduce the air temperature on the pave locating in the north.
- Large and dense trees create shade. Air temperature is less in the shaded space than an exposed area (1C – 2C). Even air temperature in the shaded pave is less than the pave exposed to the sun.
- Air temperature also depends on types of vegetation used in a space. Types and configuration of herbs, shrubs and trees are important for local air temperature.
- Density (trees) is also an important component for reducing air temperature. Dense vegetation helps to reduce air temperature by screening solar radiation.
- Area of vegetation affects the local air temperature. Large area of vegetation can keep lower the air temperature where as presence of hard exposed material or structure in the green area is responsible for increasing the air temperature.

CONCLUSION

The urban open spaces are very vital part of a city and considered more successful when these spaces can allow more people for different outdoor activities. So it is always very essential to design comfortable urban spaces for city dwellers. Dhaka is a city of hot and humid climate with high average temperature. Direct solar radiation and scorching heat of sun not allow city people to have maximum use of city open spaces specially in day time. Vegetation has great potential to reduce this air temperature (3C - 4C) of urban microclimate and ensure sustainable breathing space. Again vegetation creates shaded cool area with lower air temperature for the users. Designing an urban space with large area of vegetations on south side may create comfortable environment. Vegetation configuration can be one of major determining factors to get benefit of urban open spaces in Dhaka city with the best utilization of it, in her every aspect of urban landscape design.

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Exploring the Current Practices of Post Consumer PET Bottles and the Innovative Applications as a Sustainable Building Material – A Way Ahead

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ABSTR ACT

PET stands for polyethylene terephthalate and PET bottles are occupying an indispensable position in common man's life. Food processing industries across the world are using PET bottles as effective containers for storing juice, beer, carbonated and non carbonated drinks. The different parameters which determine the form of PET bottles during designing, manufacturing and production phases are cost per unit, need, volume, color, intrinsic velocity, size, shape etc. Irrespective of a wide range of applications, initiatives in recycling post consumer PET is sporadic. The disposal of PET bottles in the environment, significantly contributes to ecological imbalance. Interpreting the negative impacts and adopting the principles of Reuse B and C by Romans, pioneers are searching for rational and technical solutions to check this issue. In construction industry, hybrid actors are using PET bottles as moulds for developing alternative blocks. Technocrats are recycling PET products physically in to fibers, pellets and flakes for partial replacement of fine and coarse aggregates in conventional building materials. This paper intends to consolidate such initiatives addressing building systems, materials and artifacts. It discusses an overview of such applications and other intuitive trends which are emerging in Indian context.

INTRODUCTION

The technology of storing liquid products for transportation, distribution and use is defined as packaging. Our ancestors used baskets and storage units made of natural fibers and indigenous materials like stone, earth etc. Use of paper and metal plated containers for such applications dates back to the 10th century (Packing, 2012). Glass bottles, plastic containers and polyethylene are used predominantly in today's context. Polyethylene terephthalate, a versatile material is playing a primary role in packaging industry in today's context, simultaneously increasing the production process. The drawbacks during the disposal phase is raising a question, whether the invention is a boon or a bane, revolving around the societal benefits (Andrady & Neal, 2009) and the negative impacts in the environment (Webb, Arnott, Crawford, and Ivanova, 2012).

HISTORY

According to the archaeologists, a novel concept, "Post consumer packing material as a resource, specifically in construction", is traced from the Hellenistic age. Interpreting the problems posed by disposal of 'amphorae', Romans came up with an innovative idea to reuse them in architecture (Will,

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1977). While doing so, the pointed base pots were either modified or unmodified. Romans classified reuse as A, B and C (Pena, 2007). When the amphorae were used as a storing unit, it was reuse A. Reuse B and C, denoting the applications in other fields without modification and with modification respectively. The beginning of 19th century witnessed similar application of glass and PET bottles in construction.

AN INSIGHT TO PET

Plastic is a commonly preferred packing material for various goods in today's fast moving contemporary world. They are classified in to seven categories based on recyclability (Society of plastics, 2013) and polyethylene terephthalate denoted as PET, PETE or PETP ranking number one. The credit of inventing PET goes to chemists Whitefield and Dickson, the employees of Calico Printer's Association in 1941 and was patented only in 1973 by Wyeth. Semi crystalline thermoplastic polyester, durable, low gas permeability, chemically and thermally stable, easily processed and handled, transparent, wear and tear resistant and non biodegradable are the general characteristics of PET. Based on its versatility, it is primarily used in textiles, films, utility ware, sportswear etc. Food processing industries prefer PET as it is hygienic, strong, lightweight (Petresin, 2013) and devoid of phthalates, dioxins, bisphenol A, cadmium, lead and other endocrine disruptors (NAPCOR, 2013). As PET is used predominantly in the form of bottles for storing carbonated and non carbonated drinks, this paper addresses to reuse the PET bottles in construction industry.

PET BOTTLE

Cap, neck, shoulder, body, hip and feet are the basic parts of a PET bottle (bottle biology, 2013). Containers for storing carbonated and non carbonated drinks have different intrinsic velocity, wall thickness, color and level of copolymer. With respect to the physical form, PET bottles used for storing carbonated drinks are designed with an additional twist in the neck, thicker wall, higher intrinsic value, lower copolymer level and a petaloid base (Bristogianni, 2012).

POST CONSUMER PET – REUSING VS RECYCLING

According to the Environmental Protection Agency, recycling, incineration and landfill are the general ways of disposing plastics are disposed in today's context. Each method has its own disadvantages and drawbacks (Webb et.al, 2013). Its disposal is disturbing the ecological balance, directly or indirectly affecting the health of all living creatures (Rustagi, Pradhan & Singh, 2011).

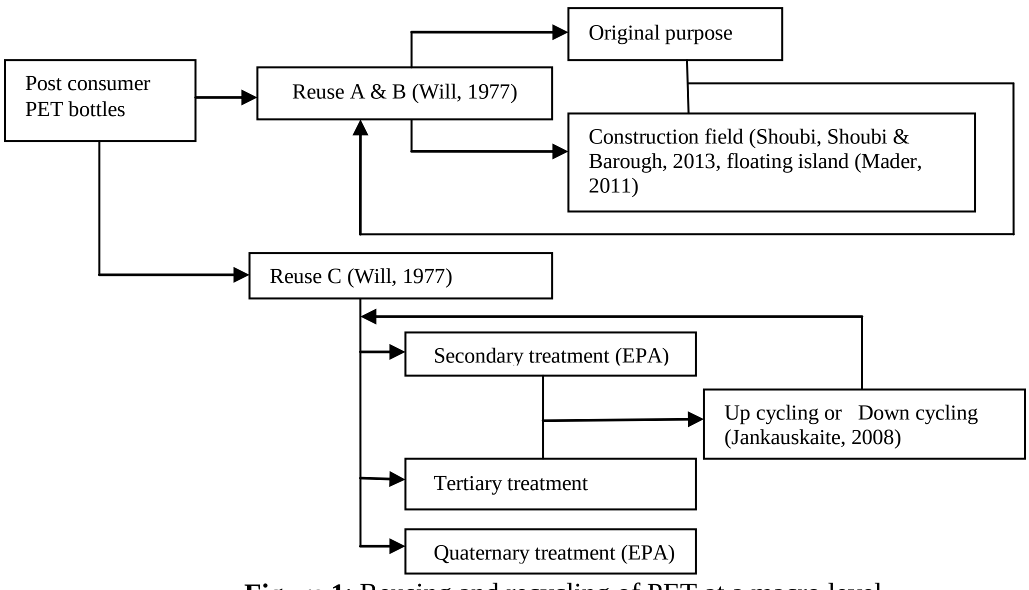


Figure 1: Reusing and recycling of PET at a macro level

Recycling is classified as primary – re extrusion of pre consumer scrap; secondary or physical or mechanical treatment; tertiary or chemical treatment where the chemical structure is altered and quaternary treatment, focusing on energy recovery. Reusing is the most preferred option as the consumption of energy and resources are always less (Al-Salem & Baeyens, 2009) as in Figure 1.

Reusing PET bottles for packing continuously is not preferable; however the idea of reusing them in a different field requires innovation. PET bottle bricks as an alternative building material, a less energy intensified process, is successful in construction process. A rational and a pragmatic perception is the requirement in today's context to address multifaceted issues simultaneously.

POST CONSUMER PET AND THE AVANT-GARDE PERCEPTIONS

Innovators and researchers are adopting different strategies to reuse and recycle PET bottles. Up cycling and down cycling are the processes involved in the manufacturing of new products with the treated PET bottles. While applying such concepts, the consumption of energy and the negative impacts generated during the production phase need to be kept to the minimum. Investigations on effective reusing or recycling of such used bottles in the construction sector, marks the beginning of the next industrial revolution. A holistic, pragmatic approach rich in aesthetic values (Pramar, 1973), as the focal point, the vision of the architects and environmentalists, technocrats, product designers and artists are interpreted in Table 1.

Table 1: Unique perceptions

Post consumer PET bottles	Hybrid actors - Holistic	Technocrats- Rational approach	Product designers- Innovations	Artists-Aesthetic expressions
Unmodified / Reuse B Modified / Reuse C (secondary and tertiary)	Partly objective and subjective, Aesthetic values	Objective, Economical, Utilitarian	Subjective, Partly functional and Emotional	Subjective, Aesthetic, Emotional
Approach	Ecocentric	Problem solving	Transforming the overlooked	Promoting Awareness
Examples	Bottle bricks with different fillers, PET bottle as a filler	Partial replacement in building materials	Screens, lamp shades, planter boxes, chandeliers, furniture etc	Murals, sculpture

EXPLORING THE 'ECOCENTRIC' APPROACH

'Ecocentric' approach is one among the six competing logics of sustainable architectural practices - built forms are parasitic in nature and revolve around the post consumer waste (Guy &Farmer, 2001). With self sufficiency and incorporating the principles of a living organism, Reynolds designed 'earthships' in 1970s. With his attitude towards post consumer waste as a resource, he developed building systems by using tires, glass bottles and aluminium cans. Creating the base for a man made floating island (Mader, 2011) with PET bottles is an exceptional eco centric idea.

Interpreting the role of PET bottles and 'Reuse B'

Following Reynolds' strategies, Froese initiated to construct small structures with PET bottles firmly held in position with nylon ropes in 2001 (Pachecho, 2013). PET bottle buildings are bio climatic, cost effective, non brittle, easy maintenance, resistant to abrupt shock loads; strong, durable, versatile, easy handling and reusable are the characteristics of such built structures (eco tec, 2002). Habitable spaces, activity centers, learning centers and latrines are constructed using PET bottle bricks at Honduras, Nigeria, Central America, Philippines and India. Architects and technocrats are searching for a variety of solutions to reuse post consumer PET bottles in building envelopes for permanently built forms, temporary structures and interiors as in Figure 2.

With a holistic approach, PET bottle bricks are being made with a variety of filling materials such as adobe or sand (eco tec, 2002, May 4), liquefied adobe, inorganic waste (Saraswat, 2013), sand and cork (Shoubi et al, 2013). PET bottles are stacked one on top of the other to build green houses (Alvarado, 2010). When adobe is used as a filling material in PET bottles, it should be tightly compacted with a stick as well as a compressor and then tightly closed (Can steel, 2014).

A unique brick with PET bottle itself as filler (Mehta and Ellis, 2007) is developed by Lima. Bottles are effectively used to replace the concrete in roofs and investigations on the monolithic casting of such discarded transparent containers is in the progress (Radu & Christiana, 2011) and as fillers in slabs (Pandya, 2012) as shown in Figure 2.

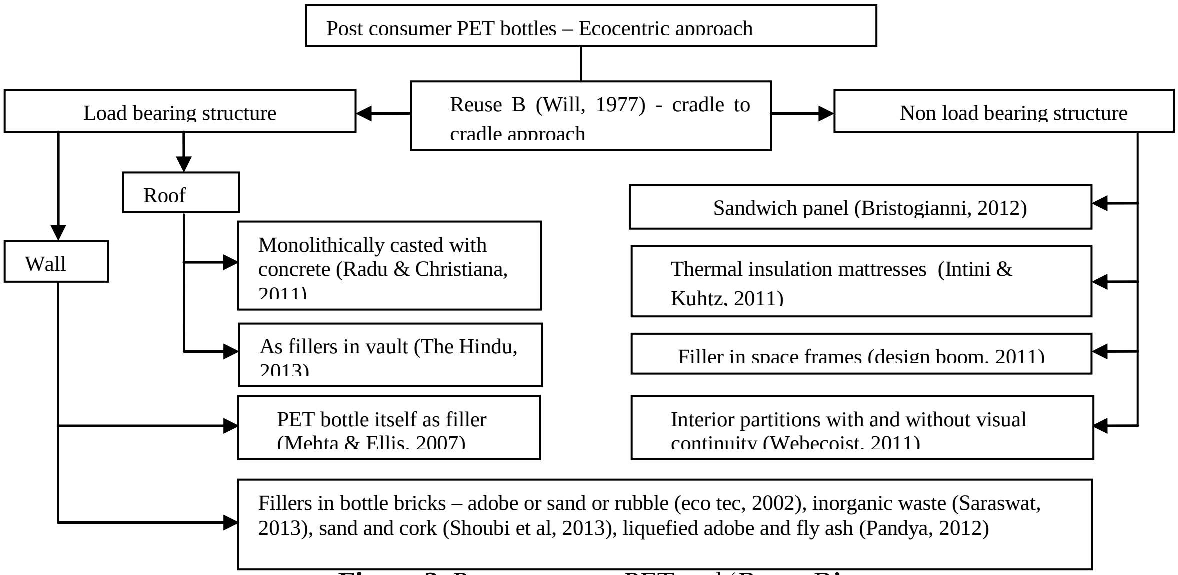
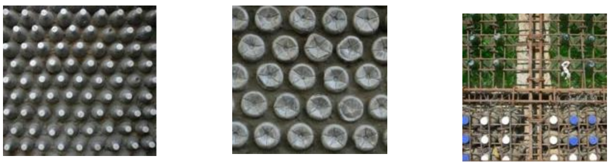


Figure 2: Post consumer PET and 'Reuse B'

They are used as sandwich panels in the constructing emergency shelters (Bristogianni, 2012), as partitions with and without visual continuity and also as fillers in concrete roofs and space frames changing the perception of 'post consumer packaging waste. PET bottle partitions, designed in Danone office and in Morimoto restaurant, is a value addition initiative. In Morimoto restaurant, experiencing the two storied partition integrated with LED lights is a unique idea, bewildering the visitors to think about the workmanship and material (webecoist, 2011).

PET bottles and 'Reuse B' in Indian context

In a country like India the development is uncontrolled, unorganized, use of virgin construction materials increasing day by day increasing the proportion of the shelterless. Architects and others are adopting the ideals of ecocentric practices, zoning on the experimentation (Chan,2007) with post consumer waste. According to Antonoides (1992), materials are the flesh, bones and skin of the built forms and are categorized based on their influence on the structure and function. Initiators like Yatin Pandya, Prashant Lingam and Patrick San Francesco are the eye openers to experiment with post consumer PET bottles in constructing small scale buildings like activity centers, learning and habitable spaces for social causes in different Indian contexts.



(a) (b) (c)

Figure 3: (a) Front elevation (b) Rear elevation (c) PET bottles as fillers in roofs

A multi activity center at Ahmedabad by Yatin Pandya, Principal architect, Footprints EARTH, firmly believing in recycling waste as environmental, economic and architectural imperative as one of the sustainable principles, is playing a vital role in building the centre with waste materials. PET bottle bricks filled with fly ash are one of the materials for the envelope. A technique of using PET bottles as fillers in flat roofs and as bricks in walls integrated with aesthetic values as in Figure 3.

Hyderabad based entrepreneurs Prashant Lingam and Aruna, designed a prototype shelter using bamboo and PET bottle bricks covering an area 225 square feet. Bamboo is used as structural members and nearly four thousand PET bottles with earth is used in the construction. A typical bonding with bottle bricks is shown in Figure 4. They are aspiring to promote this as a model house under Indira Awas Yojana, a scheme initiated by the Government of India for housing.

(a) (b)

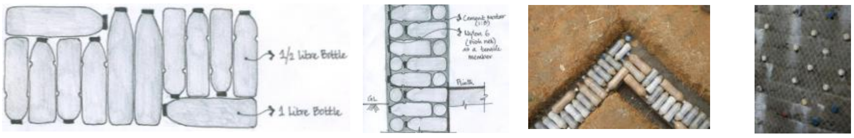
Figure 4: (a) A model house (b) a typical course of PET bottles

In Delhi, a learning centre as shown in Figure 5 was constructed by a non government organization, 'Samarpan Foundation' founded by Mr. Partick San Francesco using six thousand PET bottles with a prefabricated roof. A typical bonding is developed using one liter bottles for walls as well as flooring. The designed space roofed with simplified steel trusses and prefabricated sheets.

(a) (b) (c)

Figure 5: (a) Alternative courses with PET bottles (b) PET bottles and flooring (c) School

A model house of area 250 square feet is constructed using PET bottle bricks in Chennai. Figure 6 shows the unique bond developed by the Foundation, replacing steel reinforcement with 3cm X 3 cm Nylon 6, to improve the tensile strength. Techniques for constructing a vault and flat slab using PET bottles are developed. For the construction of one cubic feet volume of load bearing wall we require sixteen half liter bottles and nine one liter bottles.



(a) (b) (c) (d)

(e) (f) (g)

Figure 6: (a) Typical course (b) Typical section (c) L Junction (d) 3cm X 3cm nylon 6 for additional tensile strength (e) Vault construction (f) Flat slab (g) A housing prototype

In our University Campus, we in collaboration with Samarpan developed a typical bond for the construction of a compound wall as shown in Figure 7. Further, PET bottle columns, where three half liter bottles and one liter bottles are stacked vertically in a typical course with nylon 6 as the reinforcement, runs around the column in clockwise and anticlockwise direction as shown is casted at the Council of Scientific and Industrial Research, Chennai for structural and seismic investigation.

(a) (b) (c)

Figure 7: (a) & (b) Footing for compound wall (c) PET bottle column

ROLE OF PET IN 'REUSE C' FOR DEVELOPING ALTERNATIVE BUILDING MATERIALS

Innovative applications of physically recycled post consumer PET

The secondary recycling is classified as physical reprocessing, melting and reforming. Investigations on mechanical, thermal, electrical, light weight properties of such materials with physically modified PET granules, pellets, fibers as partial replacement for fine or coarse aggregates are progressing. Such developed materials and composites are effectively used in pavement and roads.With respect to melting and reforming or re engineering, PET bottles with inherent interlocking property are designed and developed by Miniwiz with properties like translucent, insulating, light, strong and mechanically recyclable material. It is created in order to tackle three environmental problems – waste accumulation, resource scarcity, greenhouse gas emissions simultaneously (Hegenwald, Ackermann, Neugebaue, Finkbeiner, 2013). Reusability, recyclability, non toxicity, low volatile compounds, on site production, scratch resistant, easy maintenance, simple installation and affordability are the distinctive features of this building material (Miniwiz, 2011).

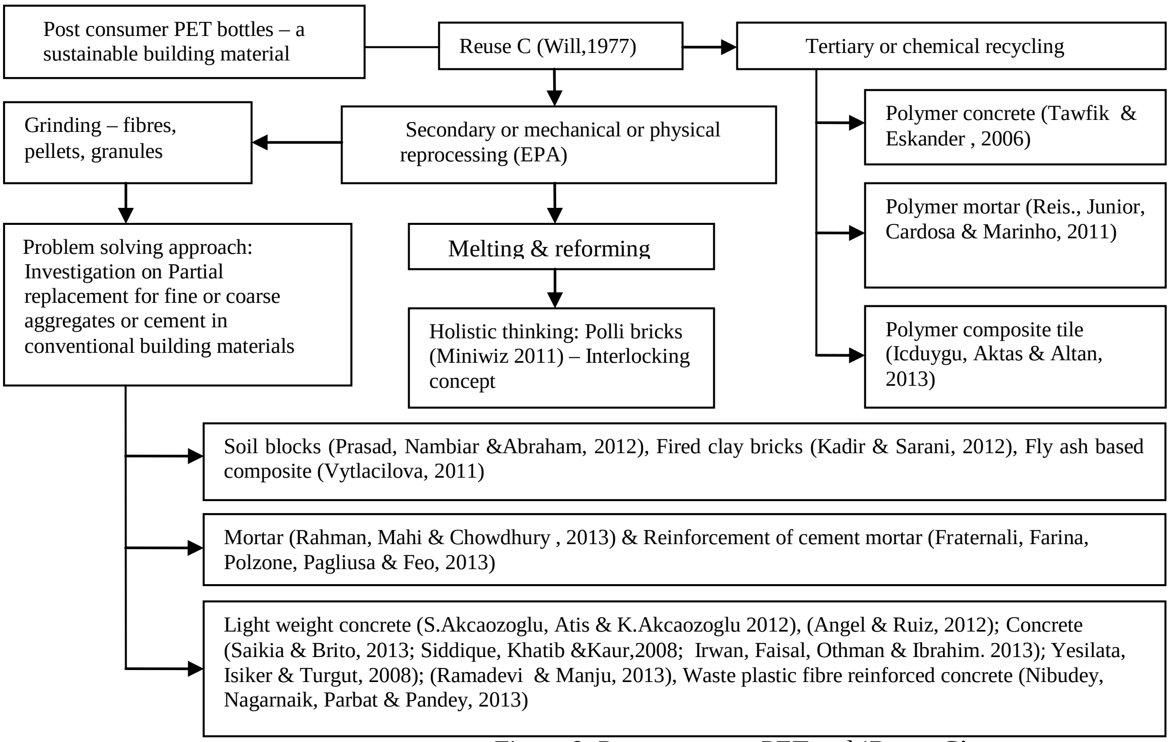


Figure 8: Post consumer PET and ‘Reuse C’

Innovative applications of chemically recycled PET

Investigations on polymer concrete (Tawfik & Eskander, 2006), polymer mortar (Reis et al, 2011) or polyester composite tiles (Icduygu et al, 2013) are emerging, where the chemical composition of the PET is modified through chemical treatment as in figure 8. Applications in the construction of habitable spaces need to be addressed and impacts created during the treatment and production phase is to be investigated.

CONCLUSION

The initial perception on the use of PET bottles in construction is changing day by day. A paradigm which emerged as PET bottle bricks in the construction of load bearing walls with steel trusses and prefabricated metal sheet is at present witnessing flat roofs with nylon 6 replacing steel reinforcement and intuitive vault construction. Apart from this ingenious bonds and columns using PET bottles gives a new direction to think about beams, foundation and simple trusses. With a holistic approach, designing phase of PET bottles with interlocking property is innovative. Even though research on the effective use PET in developing new material as an option, solutions exploring the application of PET bottles as structural members, foundation, retaining walls and secondary elements like street furniture, kerbs, road dividers, pavements and other landscape elements is to be looked in to. Strategies, approaches and practices integrating the relationship incorporating a total rethinking on junk as a resourceful building material integrating waste need to be nurtured and shall be enhanced. The Governing bodies shall formulate policies to propagate this eco centric approach via appropriate practices, research investigations on the properties of the materials and construction techniques.

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Study on Passive Energy Efficient Retrofit of Existing Buildings in Humid Tropical Area: Summery and Extension based on Research in Lingnan Area of China

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ABSTRACT

The paper describes the climate, the thermal comfort and the key points to strengthen the buildings' climatic adaptability in Lingnan area of China, which is a part of the geographical distribution of the world's hot and humid area. Based on this, it makes a summery and extension of some general possibilities for passive energy efficient retrofit of existing buildings in humid tropical area.

At present there are around 50 billion Sqm existing buildings in China. Most of these have some problems such as high energy consumption, conflict between function and space, and improvement demands for environmental condition. It is practically significant to discuss the energy efficient retrofit under reasonable cost control.

There are passive technology and active technology in energy efficient retrofit. Passive technology means certain architectural methods that make the buildings stronger in regulation and adaptation to the climate. It is low-skilled, less in investment, easy to manage, as well as universal and durable, therefore suitable for low-cost promotion in large number.

The Lingnan Humid Tropical Area has similar climatic characteristics, such as hot summer and warm winter, humid climate and abundant rainfall. One significant is that the high temperature and the humid weather come up almost over the same period. The buildings have similar features in passive design for climatization, therefore there are certain rules to follow.

The paper introduces a case of energy efficient retrofit in this area, and sum up several passive technologies used in the case, and evaluates how it affects on economic and environmental benefits.

Finally, based on this, the paper makes a summery and extension by listing several strategies for existing buildings passive energy efficient retrofit in humid tropical area, and generalizing several passive energy saving possibilities on four different level: environment, space organization, material and structure, use and management of the buildings.

KEYWORD

Humid Tropical Area, Existing Buildings, Passive Technology, Energy Efficient Retrofit, Lingnan

PRESENT SITUATION OF EXISTING BUILDINGS AND THE NECESSITY TO RETROFIT

According to a statistical data from the “Existing Buildings Retrofit Evaluation Criteria” preparation group of China Academy of Building Research in June 2013, there are around 50 billions square meters of existing buildings in China. Most of these have some problems such as high energy consumption, conflict between function and space, and improvement demands for environmental condition. Strategies need to be taken to ameliorate the situation immediately.

Buildings in developed countries have got long service life and always been reused well. In America, buildings have an average service life of about 80 years. Over 70% of the construction works are related to old buildings reuse. However, the number in China is shorter than 30 years. Annually, demolition of old buildings equal to almost 40% of the new construction area. There is 0.8t carbon being released when 1 ㎡ new area is constructed. As a result of the rapid urban development and updates, recurrent demolish and construction of building industry, It has been a vicious cycle of resources waste and environmental pollution. Appropriate retrofit of existing buildings can bring lots of positive results, such as less investment, shorter construction period, cost saving, environmental improvement, construction waste reducing and the low-carbon business.

BRIEF INTRODUCTION FOR PASSIVE TECHNOLOGY

Generally, there are passive and active technologies in energy efficient retrofit. Passive technology means architectural methods that make buildings stronger in adaptation to climate. It relays on natural energy such as sun radiation, to satisfy normal operation and improve the indoor comfort. It requires organize the building elements such as function and form synthetically. These measures are closely related to the site environmental and climatic conditions, so manifest in various forms in different area.

It is low-skilled, less in investment, and easy to manage, as well as universal and durable, therefore suitable for low-cost promotion in large number. However sometimes we need additional active technology to make up for its deficiency to regulate. Energy efficient retrofit of existing buildings should mainly relay on passive technology and supplementary on active technology. In long-term practice, Lingnan traditional villages have accumulated lots of experience, which inspire us today, “cold lane” e.g. It is a narrow alley between two rows of folk houses in Lingnan traditional villages. Together with those patios and courtyards system in the houses, it plays an important role for sunshading and ventilation.

CLIMATIC CHARACTERISTICS IN LINGNAN HUMID TROPICAL AREA

Lingnan Area is a place in South China which is next to the equatorial. It contains Guangdong and Hainan Province, southern Fujian and eastern Guangxi Province, which is across the mid subtropical, south subtropical and tropical areas. (Figure 1)

This area has a long and hot summer but short and warm winter. The annual sunshine hour is around 1800h to 2100h, which ranges from 40% to 50% in full year. The sunshine period is not long but both direct radiant and scattering are intense. The annual noon minimum incidence angle is about 41° . The average air temperature is 21℃ to 24℃ in full year, 28℃ to 29℃ in the hottest month, and 14℃ to 17℃ in coldest month. Extreme maximum temperature can reach 38~42℃. There is abundant rainfall, around 1700mm annually. The monthly air relative humidity is 65% to 85%. The hot and humid weather come up almost over the same period, from April to October.

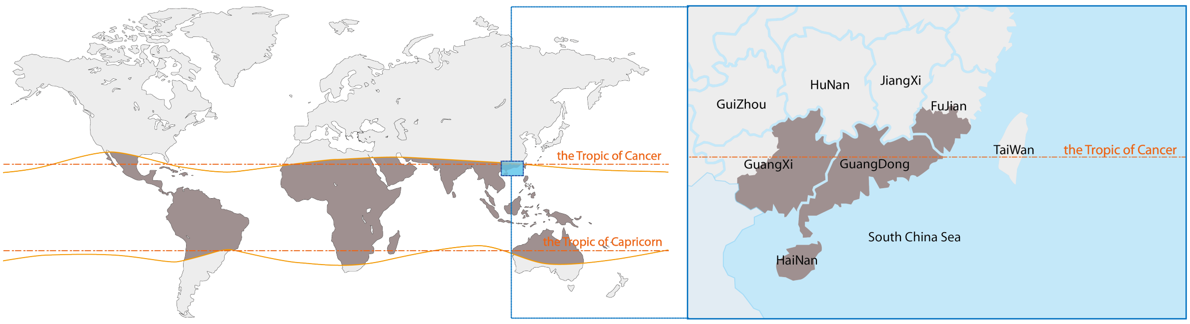


Figure 1 Location of Lingnan area in geographical distribution of the world's hot and humid area.

KEY POINTS FOR BUILDING ENERGY SAVING IN LINGNAN HUMID TROPICAL AREA

Lingnan area is close to the equatorial, so the solar radiation is intense. Therefore sunshading is needed to prevent the buildings from being heated directly. The summer is humid as well as hot, so that all outward interfaces are heated strongly by scattering. Therefore it is necessary to improve the thermal performance of the building envelope. Ventilation can help to bring away the heat as well as prevent moisture indoor. Furthermore, cooling down the building and its circumstance is good for improving the thermal environment of activities space. Sunshading, insulation, ventilation, cooling are the key points to improve the thermal environment. Other measures such as daylighting also help to save energy.

CASE STUDY: ENERGY EFFICIENT RETROFIT OF THE HEADQUARTERS OF CHINA MERCHANTS PROPERTY DEVELOPMENT CO.LTD

Case Overview

The project is located in Shenzhen. Originally it is a factory of RC frame structures, built in 1980, with 4 floors and a total construction area of 16200 Sqm. It used to be a factory of SANYO for producing electronic products, until the company moved out in early 21th century. Later the empty building was acquired by the China Merchants Property Development co.ltd and transformed into an office building for 500 employees. The retrofit design carried out from 2006 to 2007 before the project was completed in June, 2008. After the project, the building has 5 floors and a total construction area of 24260 Sqm, including 4600 Sqm area of parking garage. (Figure 2)

Figure 2 Location of the Headquarters of China Merchants Property Development co.ltd.

Design Strategy

The design strategies used in this project include both passive and active technologies. The former can be summed up on four levels. (Figure 3, 4)

1. Environmental level. Strategies include: increase the green, set up artificial wetlands and a landscape pool, use water-seepage ground material, create a three-dimensional green area on the retracted roofs in north side. These methods bring about a cool protective layer that can reduce thermal radiation to indoor.
2. Space organization level. By removing part of the original floor, the building obtains high space on outer layer, which will not affect the indirect lighting for inner rooms. The atrium in the middle helps to improve ventilation and lighting.
3. Material and structure level. The building uses fixed level sunshading panels made of silver-white metal in south facade, inner roller shutter windows in east facade, boston ivy with steel mesh as eco-shading in west facade. Hollow Low-e glass is used for the glass curtain wall. Those reserved original 240mm clay walls are added with aerated concrete block inside and coated with light-colored exterior paint. Solar panels are arranged on roof, which make use of solar and act as roof-sunshading simultaneously.
4. Use and management level. Those rooms that are less frequently used, such as multifunctional hall, are arranged on the upper layer, as a thermal insulation layer. The same principle is used in the meeting and reading rooms in south side. A high exhibition hall is added to the north, which contributes to promoting ventilation. The parking garage in basement makes good use of the spaces of poor lighting and ventilation. The office is disposed inner, surrounding the atrium.

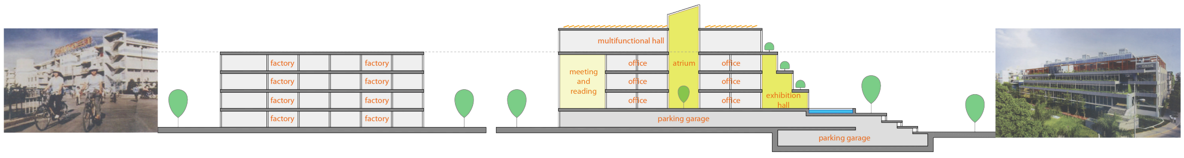


Figure 3 Photos and Sections before and after the Retrofit

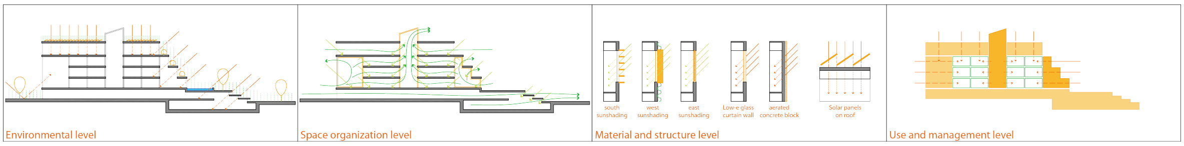


Figure 4 Design Strategies on Four Levels

The retrofit also uses several active technologies, such as air-conditioning fresh air system, high-efficient lighting, energy-saving elevator, etc. These methods also make great effects.

Energy Saving Effect

Considering the building energy consumption characteristics of this region, the air conditioning energy consumption is selected as building energy evaluation index. This building contains 16259 Sqm air-conditioning area. It's equipped with 1 High temperature chillers, 9 liquid desiccant dehumidification new air units, 350 dry fan coils, 1000 Sqm cold radiation capillary, and 2800 Sqm VRV multi-unit air conditioner. According to the building energy consumption monitoring data provided by the China Merchants Property in 2011, the Total annual energy consumption of unit construction area is 66.7 kwh/ Sqm•y, while the number of the other Grade A office buildings in Shenzhen is around 140-200kwh/㎡•y. It means that the total building energy-saving rate has reached 52.4%-66.7%. According to an energy simulation calculation by DEST and DOE2, about 27.3% of the energy-saving rate is obtained through passive methods. Using passive way in this retrofit project contributes to saving around 326,000-592,000 kwh of electricity annually. (Table 1, 2, the air-conditioning area is calculated as 16259 Sqm)

Table 1. Building Energy Monitoring of the Headquarters of China Merchants Property Development co.ltd (in 2011, Data reorganized from the China Merchants Property)

Project	Quantity		
Use area of all types of air-conditioning equipment (Sqm)	Unit A	Unit B	Unit C
	13180	2800	279
Total annual energy consumption of air conditioning (kwh)	790000		
Sub annual energy consumption of air conditioning (kwh)	620000	100000	70000
Sub annual unit energy consumption (kwh/ Sqm • y)	47.4	35.7	259.0
Annual unit energy consumption of air conditioning (kwh/ Sqm • y)	31.6		
Total annual energy consumption of the building(kwh)	1650000		
Annual energy consumption of unit construction area(kwh/ Sqm • y)	66.7		

Annotation: Unit A=Temperature and humidity independent unit
Unit B=VRV air conditioner
Unit C=Constant temperature and humidity unit

Table 2. Proportion of Passive Technology Contributed to Energy Saving (Data reorganized from the energy simulation calculation through DEST and DOE2, Lin Wusheng)

Project	Energy – saving contribution rate (%)	Sub Projects' saving rate relative to the proportion of the Total energy saving rate (%)
Envelope structure	12	18.2
Air conditioning	30	45.5
Natural ventilation	6	9.1
Electric lighting	16	24.2
Renewable Energy	2	3.0
Total	66	100

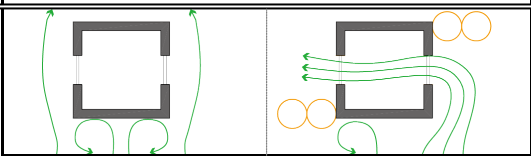
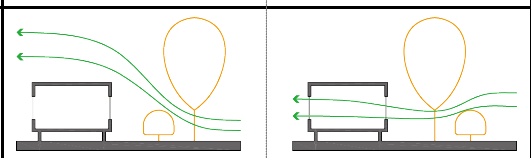
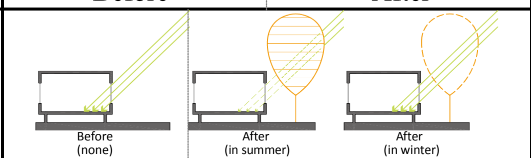
Annotation: rate (Passive methods) = rate (Envelope structure) + rate (Natural ventilation)

SUMMERY AND EXTENSION: PASSIVE TECHNOLOGY FOR ENERGY EFFICIENT RETROFIT OF EXISTING BUILDINGS IN HUMID YROPICAL AREA

Lingnan area has climatic characteristics similar to other hot and humid area. So the strategies can be applicable generally. Based on the study above, we make a summery and extension for passive technologies for energy efficient retrofit of existing buildings in humid tropical area on four levels:

1. Environmental level. Many elements of environment can be improved, such as the plants, water, ground pavement, etc. Adding or adjusting plants can help to wind-guide and sunshade. Grass brick, absorbent brick or planting ground, instead of concrete have better evaporation permeability, which contributes to regulating thermal comfort. Overheading the bottom of the surrounding buildings is effective to improve the environment ventilation. (Table 3)
2. Space organization level. Potentials for energy saving on this level can be excavated by space addition, subtraction and reorganization. Atrium and courtyard inserted into the existing space can improve ventilation and daylighting. Air-pulling shaft set up with existing staircase in high-rise buildings help to form the Venturi effect. Increasing of gray space like outdoor gallery and balconies is beneficial for ventilation and sunshading. Body ways such as over-handing, make conditions for self-shading. Size variation of the interior space can adjust indoor air pressure for air floating. Unnecessary partition walls that block wind flow should be taken away. (Table 4)
3. Material and structure level. Energy saving on this level mainly target on the building envelope. Various forms of sunshading can improve the comprehensive shading coefficient. Mosoon window is favourable for humid tropical area because of its excellent function for ventilation. Using energy saving glass for windows can improve insulation. Affixing ceramic tiles, coating with light-colored paint, adding green to the outer surface, or double skin wall can help to improve the heat transfer coefficient. Wind-guide wall added on outward can guide wind into the building. Adjusting the vents on outward interface help to make optimum ventilation and a homogeneous wind field. Water-storing roof, planting roof or shading on rooftop can reduce heat transfer. Skylight improves daylighting and ventilation both. Adding eco-epidermal to an existing building can strengthen its climate adaptability. (Table 5)
4. Use and management level. Space we use is not absolutely static. It can be adjusted to be better climate-adaptive. For instance, site the main space in the upwind sides, so to make good use of the windward, while the auxiliary space in the west as insulation layer. Open or close the atrium according to season to form chimney effect in summer and insulation effect in winter. Activity venue should be adjusted according to the comfort change of indoor and outdoor. (Table 6)

Table 3. Summarized Passive Retrofit Technologies on Environmental level.

Object	Instance	Schematic diagram	Major effect
Plant	Adding plants along the north side can help guide wind into the building	 Before / After	Ventilation
	Adjusting combination of the trees and shrubs can change the air path and guide wing into the building	 Before / After	Ventilation
	Planting deciduous trees in the direction of sunlight, would help shade solar radiation in summer but allow sunshine in winter	 Before / After	Sunshading

reserved elements　retrofit elements　water　wind　sunlight　heat

Refer to Table 3 (continued)

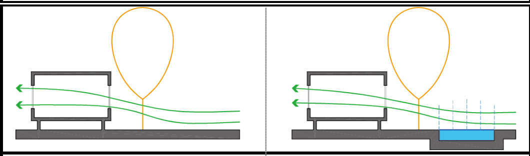
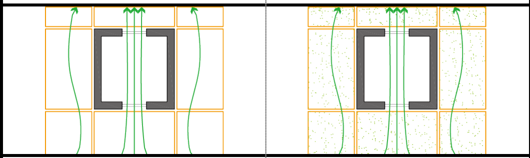
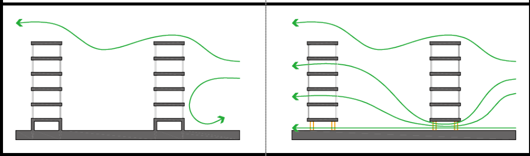
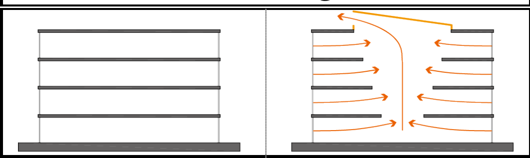
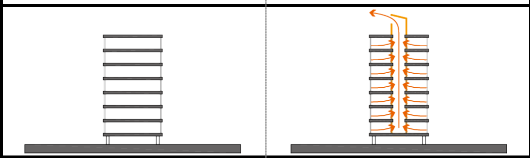
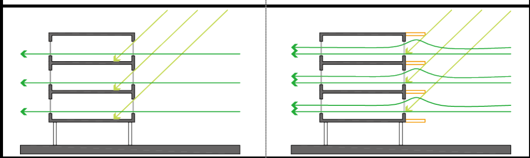
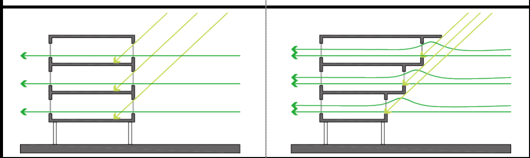
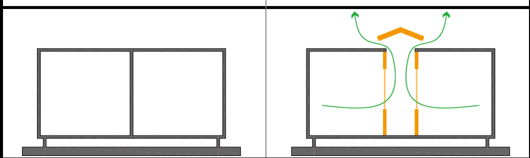
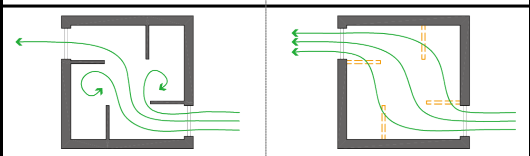
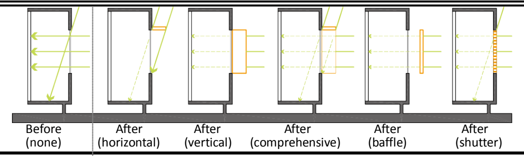
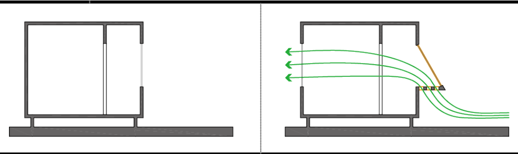
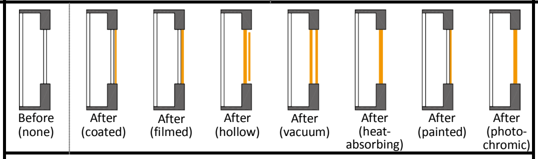
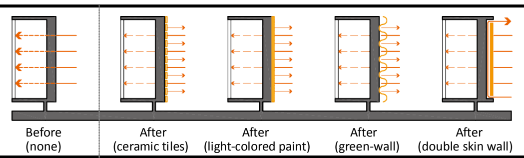
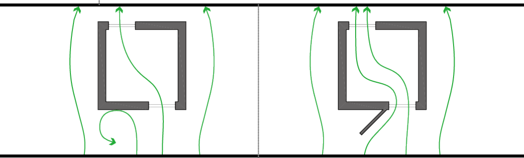
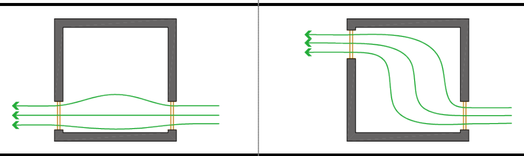
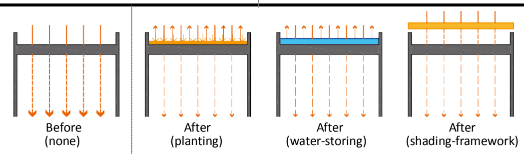
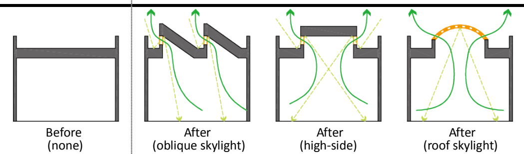
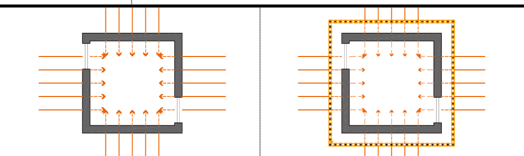
Object	Instance	Schematic diagram	Major effect
Water	Water arranged help to improve microclimate through evaporative cooling. Temperature difference that caused also benefits ventilation	 Before After	Cooling Ventilation
Ground material	Grass brick, absorbent brick or planting ground have good evaporation cooling permeability, which help to regulate thermal comfort	 Before After	Cooling
Surround-ing buildings	Increase overhead rate of the buildings' bottom is effective to improve environment ventilation	 Before After	Ventilation

Table 4. Summarized Passive Retrofit Technologies on Space organization level.

Object	Instance	Schematic diagram	Major effect
Atrium, Courtyard	Atrium and courtyard can be inserted into the existing space to improve ventilation and daylighting	 Before After	Ventilation Daylighting
Air-pulling shaft	In high-rise buildings, air-pulling shaft can be set up together with the existing staircases, so as to form the Venturi effect	 Before After	Ventilation
Gallery, Balcony	Increase of gray space such as outside gallery and balcony can form air pressure difference, that benefit ventilation and sunshading	 Before After	Ventilation Sunshading
Body	Use body ways such as overhanging to create condition for shape-shading and guide wind into the building	 Before After	Ventilation Sunshading
Transition space	Create size variations of the interior space that form indoor air pressure difference, which help to form wind fields for better air floating	 Before After	Ventilation
Partition wall	Unnecessary partition walls should be take away so as to make room for air flow	 Before After	Ventilation

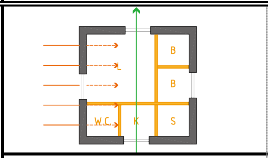
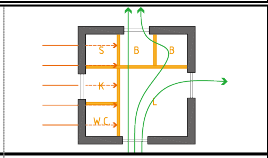
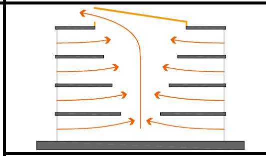
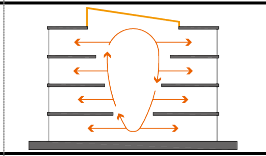
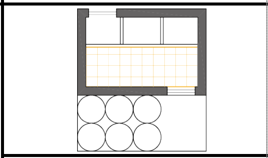
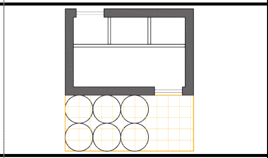
reserved elements retrofit elements water → wind → sunlight → heat

Table 5. Summarized Passive Retrofit Technologies on Material and structure level.

Object	Instance	Schematic diagram	Major effect
Doors, Windows	Horizontal, vertical, comprehensive, baffle-style or shutter, etc. can be used to improve the comprehensive shading coefficient	 Before After	Sunshading
	Mosoon window is favourable for humid tropical area because its excellent function for ventilation	 Before After	Ventilation
	Use energy saving material for windows, such as coated, filmed, hollow, vacuum, heat-absorbing, painted, and photochromic grass, etc	 Before After	Insulation
Walls	Affixing ceramic tiles, coating with light-colored paint, green-wall, or double skin wall can improve the heat transfer coefficient	 Before After	Insulation
	Adding wind-guide wall besides the vents can be helpful to guide wind into the building	 Before After	Ventilation
	Vents layout on diagonal can make optimum ventilation and a homogeneous wind field indoor	 Before After	Ventilation
Roof	Planting roof, water-storing roof, shading framework on rooftop, etc. can reduce heat transfer greatly	 Before After	Insulation
	Oblique skylight, high-side window, roof skylight, etc. are useful for daylighting and ventilation	 Before After	Daylighting Ventilation
Epidermal	Adding eco-epidermal to an existing building can strong its climate adaptability	 Before After	Insulation Cooling

reserved elements retrofit elements water wind sunlight heat

Table 6. **Summarized Passive Retrofit Technologies on Use and management level.**

Object	Instance	Schematic diagram		Major effect
Function planning	Site the main space in the upwind sides to make full use of the windward, while the auxiliary space in west, as an insulation layer	 Before	 After	Ventilation Insulation
Manually adjust	Open or close the atrium according to the season change, so as to form chimney effect in summer and insulation effect in winter	 Summer	 Winter	Ventilation Daylighting
Venue selection	Select activity venue according to comfort changes, e.g. arrange daytime activity indoor, while enjoy the breeze outdoor in the evening	 Daytime	 Evening	Ventilation Cooling

reserved elements retrofit elements water wind sunlight heat

Annotation: all the technologies showed on the tables 3-6 above just provide possibilities but not fixed pattern. We can make appropriate choices from the tables, according to the actual situation, such as the cost, feasibility or historic preservation, etc.

CONCLUSION

1. The paper summarizes the key points as sunshading, insulation, ventilation, cooling and daylighting to strengthen the buildings' climatic adaptability according to the climate and the thermal comfort in Lingnan area of China.

2. For the purpose of an understandable and practical design reference, the paper classifies the passive technologies for energy efficient retrofit of existing buildings in humid tropical area on four levels: environment, space organization, material and structure, use and management of the buildings.

3. Through a case study of energy efficient retrofit of the Headquarters of China Merchants Property Development co.ltd. The paper discusses the energy savings and economic benefits of energy efficient retrofit of existing buildings.

4. Further study may target on more specific methods for passive energy efficient retrofit of existing buildings and detail how they work, and how all the technologies react to the changing conditions of climate, social economic and the continues rapid advances in active technologies.

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Preliminary Study on Natural Ventilation for Hospital Building in Hot and Humid Regions

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ABSTRACT

This essay proposes the necessity of natural ventilation of the hospital buildings in the hot and humid regions from the perspective of energy saving. It integrates the existing natural ventilation technologies from traditional houses and other types of buildings in such area to further investigate the natural ventilation design methods for the purposes of energy saving and requirements satisfaction, thus to provide useful data for the engineering design in the future.

KEY WORDS
Hot and Humid Regions, Hospital, Natural Ventilation, Passive Design

1. INTRODUCTION

In today's world, the energy issues which are drawn more attentions worldwide are generally recognized as one of the four survival prerequisites we are facing. It is estimated that the population will come to 10 billions by the end of this century,[1] resulting in more severe conditions of energy consumption.

The energy consumption of buildings has been taking a significant proportion in energy consumption of human life. According to the experiences from industrial developed countries, the building energy consumption took a ratio of 35% in total energy consumption.[2] In China, the building energy consumption holds 1/3 of total energy consumption and is still increasing.

Being different from normal civil buildings, the hospital building is a fairly complicated form in public architectural design field involving a lot of specialties, as there are too many types of energy required for hospital operation. Based on relevant data, the hospital energy consumption is 1.6-2 times than normal public buildings.[3] Nowadays, the hospital buildings in China in fact have faced with tremendous energy consumption pressure which drives us to focus on energy-saving researches. The energy-saving hospital is not only for reducing the operation cost of hospital, but also to lighten the burden of maintenance cost for medical services.

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2. NATURAL VENTILATION DESIGN FOR BUILDINGS IN HOT AND HUMID REGIONS

2.1. Climate features

The climate in the hot and humid regions features as high rainfall amount, high humidity and temperature, strong sunlight, and violent lightening. The humidity and temperature are stable all the year. The year-around temperature is about 27℃ with large amount of rainfall, while the humidity is 80%-90%, therefore, such regions are under hot and humid conditions all the year.

Such climate condition, existing in widely areas of China, is a combination of high temperature and high humidity. The energy consumption of the buildings under this kind of climate condition inevitably become a major issue to be solved if we aim to achieve absolute conformity and modernity of architecture.

2.2. Basic design principles of the buildings in hot and humid regions

Following factors must be taken into account for the buildings in hot and humid regions: heat protection, moisture proof and good ventilation in summer; but cold proof and heat preservation in winter are not necessary. Open design is preferred in overall planning, individual design and structure processing, making good use of natural wind; the building shall avoid a western exposure with sunshade; storm rain, flood, moisture and lightening proofs shall be seriously considered.

2.2.1. Heat protection

In hot and humid regions, the temperature in summer is very high and lasts so long that heat protection is the priority task for the buildings in this area. Amongst building shading is the most effective way to isolate the heat. Many shading methods are adopted for the hot and humid regions, from large cantilevered roof used in traditional houses, "Special shading method invented by Professor Xia Shichang" that is commonly used in Guangdong and Guangxi, to modern building shade. All are designed to reduce direct radiation from the sun onto the building, while using shading structure to improve ventilation performance for heat dissipation.

2.2.2. Moisture proof

Most hot and humid regions laid along the ocean or are located where rivers and lakes are spread over, so the relative humidity in such areas are greater than that in inlands. As a result, the adjustment of humidity in the building should be considered in addition to heat protection and temperature cooling. In particular at the end of spring and the beginning of summer, necessary measures shall be taken for moisture and mould proof of the building envelope, while reducing the effects of high temperature and humidity on human body and improving indoor comfort.

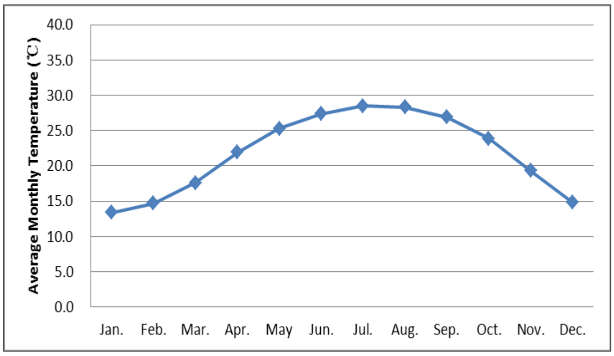
2.2.3. Ventilation

The climate characteristics of high temperature and high humidity in such area determine that the enclosing structure is not good enough to prevent solar radiation from into the room for the traditional buildings, ventilation shall be used for heat dissipation. Ventilation substantially is the flow of air, which is produced by pressure difference of air. The people living here learned a lot of experiences from their construction practices, so as to resist to those climate characteristics of high temperature, long duration, strong solar radiation and greater humidity.

3. NECESSITY OF VENTILATION FOR HOSPITAL BUILDING

Hospital building is high-energy consuming building and energy is used mainly for air condition and illumination. As a case study in Guangdong, electricity consumption of air condition is obviously seasonal, identical to the monthly electricity consumption of the hospital and the average temperature of Guangdong area. Its peak is from May to September, which is the hottest period, accounting for 50% of the total monthly electricity consumption. (Fig.1-3) In addition, the electricity consumption of air condition has a close relationship with the number of month using it. Hospitals with good natural ventilation can reduce or even cancel the use of air condition in transition season so that their annual electricity consumptions are lower, while hospitals with bad natural ventilation have to use air condition all year long which leads to a higher annual electricity consumption. (Fig.4) Electricity consumption of illumination remains the same without seasonal difference. Its difference is caused by the hospital size and the area using natural lighting only.

In summary, speaking of energy-saving of the hospital building, the energy consumption by air conditioner is the very first thing we need to discuss. If we adopt natural ventilation to reduce the burden of air conditioners, the operation costs of the hospital may be reduced as well as of the medical and health services, moreover, it provides high quality indoor air that is comfortable for the patients.



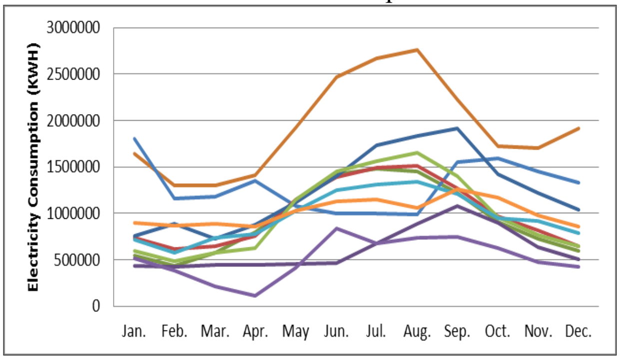
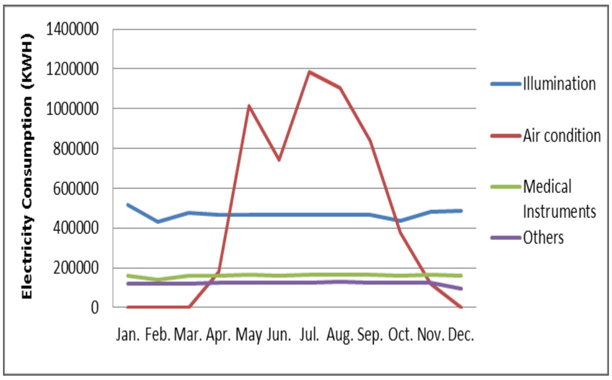


Figure 1 Monthly average temperature of Guangdong area from 1981 to 2010(Source: GangDong Weather Bureau)

Figure 2 Monthly electricity consumption of 10 hospitals in Guangdong area in 2011(Source: Drawn according questionnaire by Zhang Chunyang and Peng Dejian)



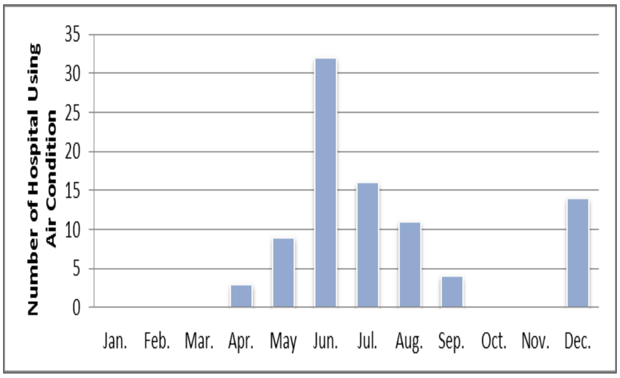


Figure 3 Monthly electricity consumption of a hospital in Guangdong area (according to purpose) in 2011(Source: Drawn according questionnaire by Zhang Chunyang and Peng Dejian)

Figure 4 Number of month using air condition of hospital in Guangdong area in 2011(Source: Drawn according questionnaire by Zhang Chunyang and Peng Dejian)

4. STUDY ON NATURAL VENTILATION DESIGN FOR HOSPITAL BUILDINGS IN HOT AND HUMID REGIONS

4.1. Natural ventilation by wind pressure

The wind pressure may be used as the main measure for implementation of natural ventilation in good wind environment. This kind of wind for ventilation by wind pressure is "Through Flow". According to the wind tunnel test: when the wind flows to the building, the positive pressure only will be generated on windward side of the building by blockage of the building. And, the negative pressure will be generated on appropriate places when the flow bypasses each side and the back of the building.The ventilation by wind pressure refers to such ventilation implemented by the pressure difference between the windward side and the leeward side of the building. The value of pressure difference is related to the form of building, the included angle of the building and the wind, and the ambient environment. When the wind flows to the front elevation in vertical way, the positive pressure at the center of windward side reaches to the maximum value, and the maximum negative pressure appears at the corner and ridge. (Fig. 5)

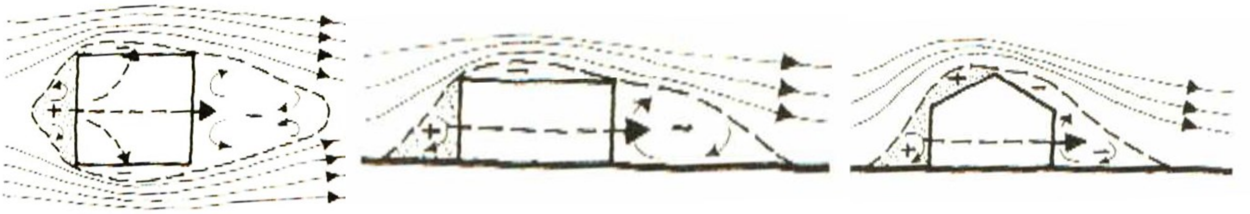


Figure 5 Principle of ventilation by wind pressure (Source: Allan Konya, Design primer for hot climates)

Another effect caused by wind pressure is the Venturi Effect. When the air flows, the flow rate will be accelerated because of shrinkage of space, thus the shrink section forms a negative pressure zone.

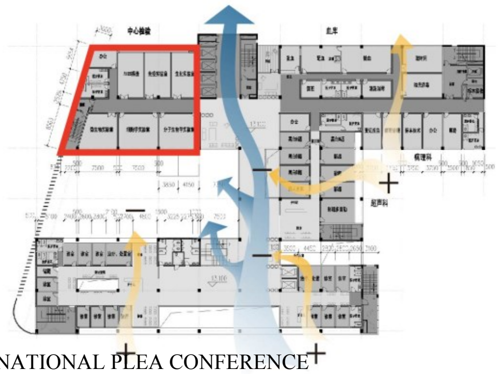
The layout suitable for such climate conditions in this area is that all rooms will be directly ventilated with goo d sunlight and the balconies or veranda shall be provided around the building. However, such space design is difficult for most of functional spaces in the hospital building. Therefore, all rooms in different position at each floor shall have ventilated air, and the through flow is required for plane design.

According to authors' experiences, there are two common strategies for hospital building design: 1. The air inlet of each functional area, as reasonable as possible, shall be placed in the dominant wind direction in summer time, without wind-shield wall, and the air outlet is placed on the other side. The inlet and outlet shall be aligned or displaced, so as to guide the air to flow into and circulate in the open plane from one side of the building. 2. Consecutive consulting rooms or wards in rows block the flowing air and shades the corridor space, therefore, the consulting room and ward shall not be arranged consecutively along the side of the building. It is recommended that some rest rooms or waiting rooms are designed in the middle of the corridor to leave the ventilation opening, so as to form through flow by wind pressure, thus to improve the ventilation performance of consulting room, ward and waiting space.(Fig. 6)

The waiting space and consulting room may be designed with courtyard concept, so that the wind can be flown into the room from the windows or holes on the building. When the courtyard window opens, the air may flow into the building for ventilation. (Fig. 7)

Secondly, take an example of bottom overhead method, which has seen more often in traditional building. The hospital building is designed to elevate the ground floor so as to improve slow flow on the ground floor and generate faster free-air speed in where is helpful for directing air flow. In addition, the air into the first floor will be in the building shadow by such overhead design, thus to reduce the air temperature and improve indoor thermal comfort. Except for some public rooms and necessary inspection rooms, the overhead design shall be available to the ground floor of hospital building as practicable as possible so that the internal building will have a better natural ventilation effect in the summer time and transitional seasons as well as a smoother process of thermal pressure ventilation. (Fig. 8)

Furthermore, the two ends of medical spaces shall not be closed, such as clinic and medical technology section, and open design is developed to generate positive and negative pressure difference at the opening of two ends of the building. Such opening is connected to the corridor, resulting in gathering and guidance of the outside air flow because of continuity of corridor, thus to improve indoor ventilation effect. The veranda assists wind guidance, also creates a comfortable zone with cool air due to shading effect, to some extent that the indoor comfort level will be increased.



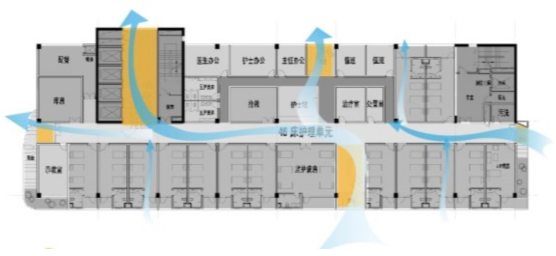
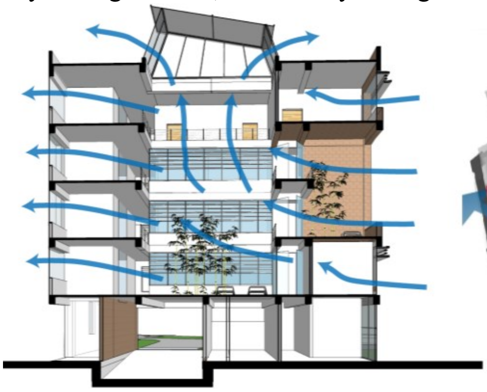
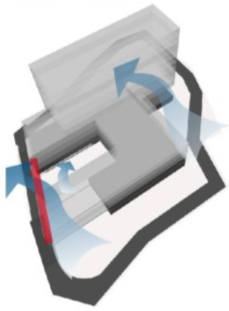


Figure 6 Schematic diagram of wind pressure ventilation in the hospital (source: capstone project by Zhong Haimin, directed by Zhang Chunyang)





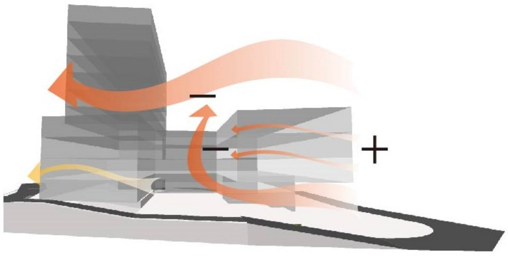
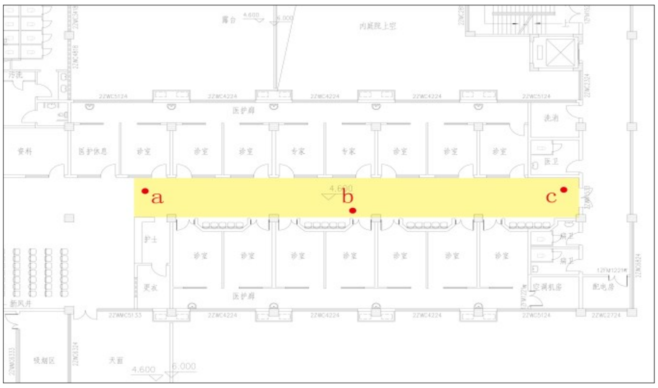


Figure 7 Schematic diagram of wind pressure ventilation in hospital courtyard (source: capstone project by Su Yanjie, directed by Zhang Chunyang)

Figure 8 Schematic diagram of bottom overhead design for guidance of natural ventilation (source: capstone project by Zhong Haimin, directed by Zhang Chunyang)

From figure 9 to 12 are measuring analysis of ENT secondary waiting area of Panyu Central Hospital without air-conditioning, outdoor maximum temperature is 35℃ and minimum temperature is 27℃ in that day. It can be known from the data in figure, in waiting area there almost has lasting natural winds, whose speed is in the range of 0.1-1.0m/s. Since the outdoor temperature is too high, the erature and humidity in waiting area are not effectively reduced too much. Moreover, as the activities of patients, the humidity in middle of waiting area is higher than the other two test points. However, according to the interview, patients in waiting area do not feel discomfortable when they are in high temperature and humidity; on the contrary, the indoor environment with lasting natural winds make them feel more comfortable.



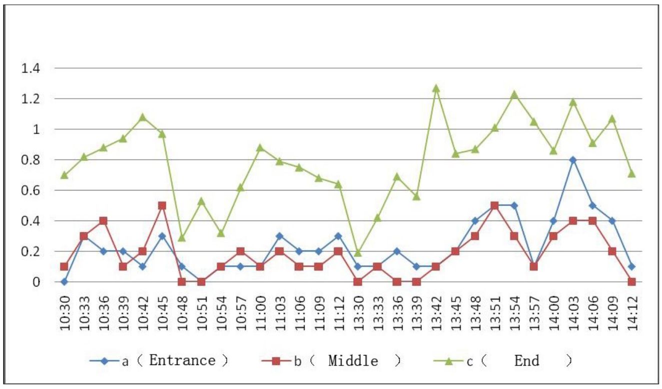
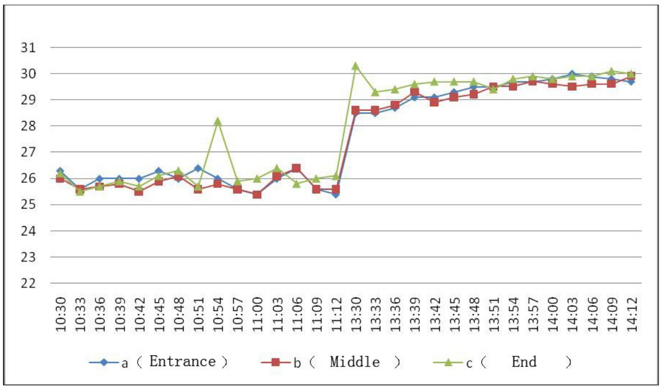


Figure 9 Measuring selected points of ENT waiting area in Panyu Central Hospital

Figure 10 Wind-speed comparison of ENT waiting area in Panyu Central Hospital



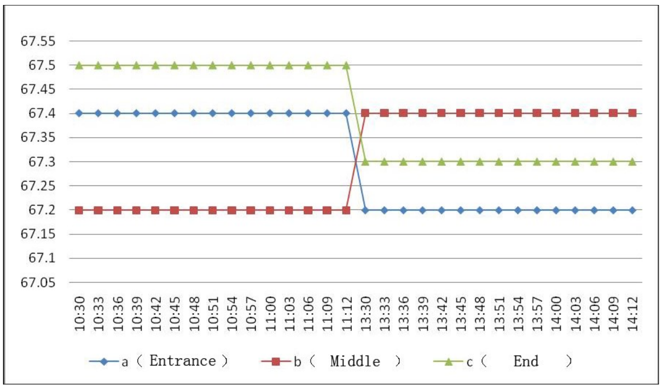


Figure 11 Temperature comparison of ENT waiting area of Panyu Central Hospital

Figure 12 Humidity comparison of ENT waiting area of Panyu Central Hospital

(Fig.9-12 source: Huang Yinjing, Study of the Natural Ventilation Strategy of Hospital Clinic Waiting in Lingnan Regions [D].Guangzhou: Archives of South China University of Technology, 2012, directed by Zhang Chunyang)

Lastly, the ventilation by wind pressure also can be achieved by design of detail structures, in order to optimize the air quality in the room and improve thermal comfort degree.

Leading wind by sunvisor:

The sunvisor is widely used in the hot and humid regions. The building sunvisor is not only able to effectively resist solar radiation, but also to change the indoor ventilation performance by adjusting the form of sunvisor and the position in the enclosing structure to improve the indoor comfort, taking the position of wind entering into the room and airflow pattern into account. For example, the louvers may change the air flow upwards or downwards when the wind enters into the room; the horizontal sunvisor on the window may direct the air flow upwards; the gap between the horizontal sunvisor and the wall may direct the air flow downwards; when the louvers are fully opened, the wind in wider area may be flown into the room. (Fig. 13)

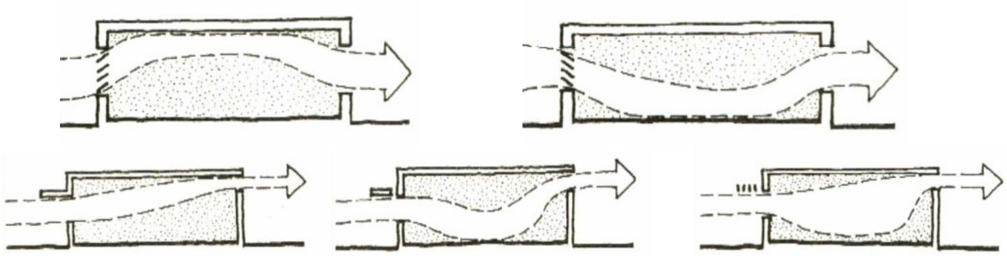


Figure 13 Leading wind by sunvisor (Source: Allan Konya, Design primer for hot climates)

Options for window opening:

Normally, these windows with greater opening and ventilation areas are selected for the hospital building. Opening out by casement window is commonly adopted because of good ventilation and greater opening areas. In case of a higher numbers of opening windows and narrow average width of opening window, the vertical hung window can be fully opened and reaches the maximum ventilation rate with air leading effect, so it is recommend as well. The doctor offices, as auxiliary function of the hospital, are always located in west-east direction, the louver (i.e. vertical hung window) is preferred to meet the requirement of wider ventilation area and direct air flow in the summer time and transitional seasons for the purposes of sun-shading and air leading effect.

In order to improve indoor ventilation performance, it is suggested that the upper ventilation window shall be set up on the partition in the corridor and ventilation louver is provided on the doorstop to reduce hot air circulation.

4.2. Natural ventilation by thermal pressure

Another principle for natural ventilation is the thermal pressure difference generated by the air inside the building, which is so called “Chimney Effect”. The thermal pressure difference in the building, namely, “Chimney Effect”, can be used to achieve natural ventilation for the buildings which are affected by the layout of surrounding buildings and tall plants. According to the principle of rise of hot air, the dirty hot air is vented out from the upper air outlet, and the outside fresh cold air is sucked from the building bottom, in order to implement natural ventilation. In building design, the vertical chambers, like stair well and atrium shall be designed to meet the elevation difference of air inlet and outlet. The higher the temperature difference of inside and outside temperatures and elevation difference of air inlet and outlet, the more obvious the thermal pressure effect. Being different from natural ventilation by wind pressure, the ventilation by thermal pressure is more suitable to the ever-changing and adversely outside wind environment.

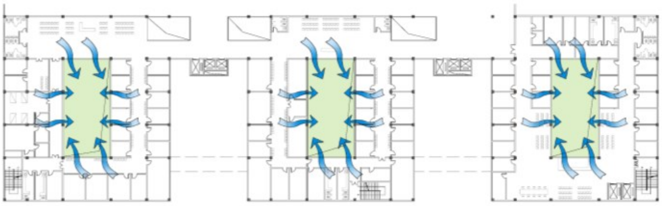
The courtyard may be designed for the hospital building in the hot and humid regions. The courtyard is one of well-known characteristics for Chinese residence. In the hot and humid regions, the traditional residences use such structure to create a good indoor ventilation condition. The courtyard design for the hospital building reflects the thermal pressure effect used by theses residences in the hot and humid regions, so as to improve the natural ventilation performance.

1. Light roof prolongs from the surface and open a window on the side of prolonged section as the air outlet, utilize and heat the accumulated air. Under heat pressure drive, the airflow is inhaled from the windows at each floor and then vent out after rise, thus to strengthen the chimney effect of the courtyard, and use the thermal pressure to provide side ventilation for the courtyard. (Fig. 14)

2. Set up exhaust chimney and increase height of air outlet, add the elevation difference of air inlet and outlet and the thermal difference of the air in the courtyard, and improve the natural ventilation by thermal pressure.

3. Combine the courtyard design to set up an integrated ventilation channel, use the courtyard space as the ecological exchange space, conduct overall design on building structure layer and courtyard space, and create an integrated ventilation channel to facilitate the natural ventilation of hospital building.

4. Set up pitched skylight to catch the wind on the windward side, and bring the outside natural wind into the courtyard to form natural ventilation; utilize the wind pressure difference of front and back of the pitched skylight on the leeside to draft the indoor air for coordination of courtyard ventilation.



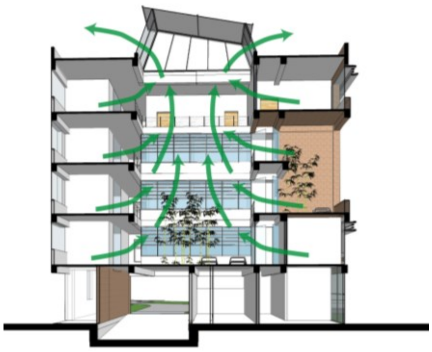
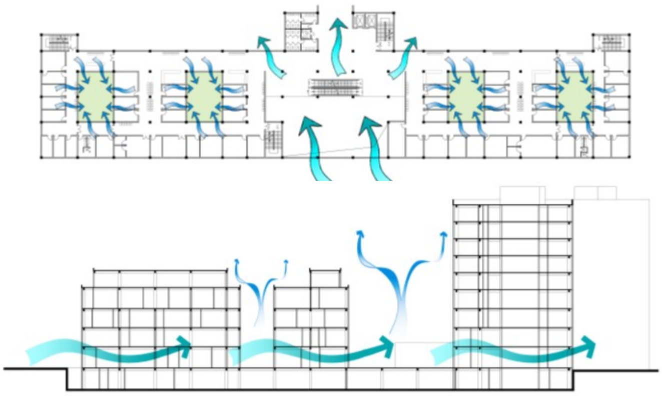


Figure 14 Schematic diagram of thermal pressure ventilation in the hospital (source: drawn by the author and capstone project by Su Yanjie, directed by Zhang Chunyang)

4.3. Combination of wind pressure and thermal pressure for natural ventilation

Due to the building is subject to the weather conditions, geographic location, ambient environment and building layout, the natural ventilation design is normally combined by wind pressure and thermal pressure in practical application. The wind pressure and thermal pressure play different roles. In the less deep sections, the wind pressure is prevail for ventilation, while in the deeper sections, the ventilation by thermal pressure is adopted. (Fig. 15)

Taking the Shenzhen Binhai Hospital as an example. There are air vents provided at the front and back of the hospital street so that wind pressure ventilation will be achieved. In addition, the top of hospital street has an elevated roof to provide a good lighting condition without direct radiation from the sunlight. Therefore, the whole elevated roof forms the ventilation by thermal pressure and eliminates the hot air on the top as well. As mentioned above, the Shenzhen Binhai Hospital is able to implement the ideal natural ventilation by combining the wind pressure and thermal pressure, thus to significantly reduce the energy consumption. (Fig. 16)



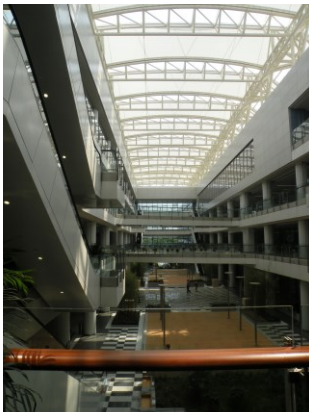


Figure 15 Combination of wind pressure ventilation and thermal pressure ventilation (source: drawn by the author)

Figure 16 Hospital street of Shenzhen Binhai Hospital (source: photographed by author)

4.4. Assisted mechanical ventilation

In some large-scale buildings, due to longer ventilation path and greater flow resistance, the natural ventilation hardly can be achieved only by wind pressure and thermal pressure. For those cities with serious air pollution and noise pollution, the direct natural ventilation will be harmful for human health when it brings the awful air and noise into the house. In this case, the assisted mechanical ventilation system is usually adopted. This system has a full set of air circulation channels, supplementing by some air treatment methods satisfying the ecological concepts (for example, soil pre-cool, pre-heat, heat exchange of deep well water, and it facilitates indoor ventilation by certain mechanical means. Comparing with fully natural ventilation, the mechanical plant with auxiliary power may consume a certain volume of energy, but this system is able to re-organize the air flow to achieve a better performance of natural ventilation.

The roof of hospital street of Guangdong Panyu Central Hospital is designed to a ventilated roof. The assisting mechanical ventilation plants, water curtains, are provided at the two sides of the roof, in order to reduce the temperature of hospital street and purify the air quality for natural ventilation. (Fig. 17)

5. CONCLUSION

The air conditioners used for hospital building in the hot and humid regions have enormous energy consumption. This essay discusses about the design strategies of hospital building in the hot and humid regions from the perspective of energy saving, and makes a contribution for constructing a energy-saving and adequate hospital building.

Figure 17 Roof view and water curtains in Guangdong Panyu Central Hospital (source: photographed by the author)

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Design Optimization of Glazing Façade by Using the GPSPSOCCHJ Algorithm

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ABSTRACT

Engineering design is a process to find the best solution to satisfy various design criteria. This work aims to optimize the glazing façade perfomance and the window size by minimizing the heating, cooling and electric lighting demand of office buildings. Accordingly, this paper presents a comprehensive analysis in order to study the balance between daylighting benefits and energy requirements in perimeter office spaces taking into account glazing properties control with window size, orientation and climatic conditions. The glazing area and thermophysical properties of the window were taken as the main variables. The optimization was carried out by using a combination of Energyplus7.0.0 and GenOpt softwares. The energy consumption can significantly change affected by geometric parameters, materials properties and types of window glass, orientation and climatic conditions. Optimum range of each parameter was calculated in order to minimize annual energy consumption with a hybrid multidimensional optimization algorithm: GPSPSOCCHJ algorithm. Furthermore, since the annual energy consumption effectively depends on the type of air conditioning system, the optimization process was carried out individually with both evaporative cooling system and compression cooling system. The results indicated that using the evaporative cooling system compared is more appropriate and economical in comparison with the compression cooling system. Also, investigations indicated that reflective double glass and low-e double glazed with argon layer glass is appropriate for Tehran office building and can respectively allocate the maximum level of window area and the minimum of energy consumption.

Keywords: Glazing façade, Optimization, GPSPSOCCHJ optimization algorithm, Energy consumption

INTRUDUCTION

Window is considered as one of the most important components influencing the thermal performance of buildings. Their shape, size, optical and thermal properties, orientation and shading/daylighting attachments determine the interior daylighting conditions as well as the visual and thermal comfort for the occupants. The balance between daylight provision and reduction in energy consumption or demand through appropriate control of solar has been investigated in a few studies by several researchers (Lee et al., 1995; Citherlet et al., 2001; Franzetti et al., 2004; Hviid et al., 2008; Tzempelikos et al., 2010). Coupling between daylighting and thermal simulation is necessary for a comprehensive analysis. In 1998, Clarke et al. compared the annual energy consumption of three different types of glazing system using ESP-r and found reductions of about 4.5%, 10.9% and 6% in maximum heating capacity, maximum cooling capacity and total energy consumption respectively.

Optimized glass facade design may improve exploitation of daylight and result in significant savings in electricity consumption for lighting. Reinhart (2002) calculated the daylight availability for several Canadian locations considering the effects of climate, external shading, facade orientation, glazing type and occupancy schedules. The study showed that location, orientation and blind slat angle all have a significant impact on daylight autonomy while external objects and glazing type were less important. Optimized glass facade design may improve exploitation of daylight and result in significant savings in electricity consumption for lighting. Reinhart (2002) calculated the daylight availability for several Canadian locations considering the effects of climate, external shading, facade orientation, glazing type and occupancy schedules. The study showed that location, orientation and blind slat angle all have a significant impact on daylight autonomy while external objects and glazing type were less important.

The sophisticated characterizations of window and shading systems sparked a large amount of studies on this topic (Reinhart and Walkenhorst, 2001; Walkenhorst et al., 2002; Robinson and Stone, 2006; Loutzenhiser et al., 2007), and various calculation models that predict illuminance on the interior surfaces of a building as well as on the work plane level are available (Mardaljevic, 2001; Fakra et al., 2011). The different models have some limitations; for example, some models use constant glass transmittance, some others use limited evaluation metrics such as daylight factors (Ghisi and Tinker, 2005); and some have limitation in sky luminance inputs. Moreover, it is complicated to modify existing software codes to adapt specific necessities or to present results using different measures. As to the latter, advanced daylighting metrics may be properly used in daylight performance evaluation (Nabil and Mardaljevic, 2006; Reinhart et al., 2006). Finally, the significant computational time, the complex calculation procedure and the inability to interpret simulation results are all factors preventing the design community from picking up the advanced design analysis schemes with very few exceptions (Reinhart and Wienold, 2011).

This study has been tried to optimize the window size and glass type with the objective of minimization of annual energy consumption function. In such a way, while reducing energy consumption, occupants' thermal comfort and the brightness level of each space remain in the acceptable range. For this purpose the modeling of thermal and visual performance of building's transparent façade is performed by EnergyPlus software and the results are optimized by GenOpt software and GPSPSOCCHJ algorithm and the effect of all parameters among solar heat gain coefficient (SHGC), thermal transmittance of window (U_{value}), and visual transmittance is considered. Finally, calculations and evaluations will lead to provide window design recommendations due to climate.

METHODS

In this paper, as shown in **Figure 1**, a case room is considered in accordance with the case No. 600 in ASHRAE 140 standard. Accordingly, this sample space is an office with the dimensions $6 \times 8 \times 2.7\ m^3$ in the middle of a tall building which only a wall with 8m width and 2.7m height is in contact with outdoor climatic conditions of Tehran. According to **Table1** the wall adjacent to the outdoor, specified by common materials for office buildings that respectively from in to out includes veneer plaster, insulation, concrete block, stucco and stone.

Table 1. The wall adjacent to the outdoor construction

field	units	obj1	obj2	obj3	obj4	obj5
name		stone	25mm stucco	concrete block	50mm insulation	plaster(light)
roughness		medium rough	Smooth	medium rough	medium rough	medium smooth
thickness	m	0.03	0.0254	0.2	0.0508	0.01
conductivity	W/m.K	3.17	0.72	0.33	0.03	0.16
density	kg/m³	2560	1856	1380	43	600
specific heat	J/kg.K	790	840	880	1210	1000

As shown in **Table2**, eight types of window glass have been considered: 6mm clear single glazed, clear double glazed with argon layer, clear double glazed with air layer, low-e clear single glazed, reflective clear single glazed, low-e clear double glazed with argon layer, low-e clear double glazed with air layer, reflective clear double glazed with air layer. Dimming of overhead electric lighting is determined from interior daylight illuminance calculated at one or two reference points. Two reference points in coordinates 3×1.6×1 m^3 and 3×6.4×1 m^3 toward the wall adjacent to the outdoor are considered as lighting evaluation criterion. Also, in order to simulate the thermal and lighting energy demands, the EnergyPlus software is used.

Table2. Types of window glazing construction

Field	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6	Obj7	Obj8
Name	6mm clear single glazed	clear double glazed with argon layer	clear double glazed with air layer	low-e clear single glazed	reflective clear single glazed	low-e clear double glazed with argon layer	low-e clear double glazed with air layer	reflective clear double glazed with air layer
Outside layer	Clear 6mm	Clear 3mm	Clear 3mm	PYR B clear 6mm	REF a clear mid 6mm	PYR B clear 6mm	PYR B clear 6mm	REF a clear mid 6mm
Layer2		Argon 13mm	Air 13mm			Argon 13mm	Air 13mm	Argon 13mm
Layer3		Clear 6mm	Clear 6mm			Clear 6mm	Clear 6mm	Clear 6mm

EnergyPlus is one of the most comprehensive whole-building energy simulation tools that are capable of modeling several features including solar irradiance and illuminance under different sky conditions, advanced fenestration systems, blind controls, indoor illuminance maps, lamp controls, and heating/cooling energy impact associated with daylighting controls (Seo et al., 2011). Building model, location and Climatic conditions design in Software environment. EnergyPlus weatherdata file is used for energy performance calculations and indoor climate analysis. Hourly based outdoor climate data (dry-bulb air temperature, relative humidity, wind speed, direct solar radiation and diffuse radiation on horizontal surfaces for 8784 hours) was used to create the model for calculation. Comparability of current study results for other climatic areas can be done through monthly and yearly average parameters which are indicated in **Table3** (Hanni.al et al., 2012).

Table 3. Reference year parameters

Month	Air temperature ˚C	Relative humidity %	Wind speed m/s	Direct solar radiation Wh/m2	Diffuse radiation Wh/m2
Jan	2.4	63	1.7	3014	1176
Feb	4.8	55	2.5	3506	1604
Mar	10.2	44	2.9	3820	1923
Apr	16.2	36	3.3	4735	2343
May	22.3	30	3.3	5859	2396
Jun	27.5	24	3.1	7640	2319
Jul	30.9	24	2.8	7632	2032
Aug	29.5	24	2.2	7234	2049
Sep	25	25	2.3	6687	1642
Oct	18.2	33	2.1	5238	1488
Nov	11	45	1.8	3959	1169
Dec	5	59	1.5	2992	1085
Avg	16.9	38.5	2.5	5193.0	1768.8

By Considering Constraints that describe below the building annual energy consumption with a focus on providing residents thermal comfort is calculated by EnergyPlus.

1. $-0.5 \leq PMV \leq 0.5$
2. The minimum illuminance required by international standards on the desk: 500 Lux
3. Heat generated within the space caused by a computer, printer and other accessories available: 800 W
4. Number of people: 4
5. Hours due to the discontinuous use: 7:00 to16:00
6. People with the metabolic rate of 100 W while seated
7. People Clothing thermal resistance, 0.6, 0.5, 0.7, 0.9 clo respectively for spring, summer, autumn and winter conditions.
8. Constant heating set point: 23.5˚C
9. Constant cooling set point: 26˚C
10. Internal gains for lights: Lighting level calculation method is used to create the maximum amount of lights to this set of attribute choices : 400 W

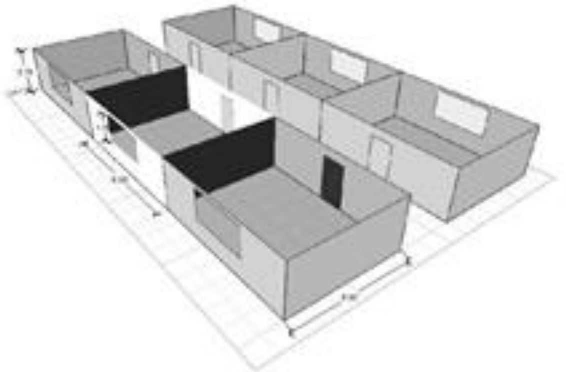

Figure 1 *Office space in the initial position study*

A key part of using optimization tools with artificial intelligence-based algorithms for optimal design is defining an appropriate objective function and constraints. In the issue examined in this article inside light level, inside temperature, sunshade dimensions, wall thermal resistance, energy consumption In order to provide lighting, heating and cooling, All are measurable quantities that can be offered based on the objective function and constraints. On the other hand, the purpose of this study was the amount of illuminanace inside the building and its thermal behavior which is obtained by minimizing the building's annual energy consumption influenced by the optimal size of the window and its different types. For daylighting control types available in EnergyPlus, optimization algorithms must support discrete (on-off or 2 or 3 steps controls) and continuous (dimming control) variables. In addition, the selected algorithm should support intrinsic approximation problems. Detailed buildings energy simulation tools such as EnergyPlus, TRNSYS, and DOE-2 involve solving a series of systems of partial and ordinary differential equations that are coupled to algebraic equations. Therefore, an optimal solution for a continuous cost function may be difficult to obtain without using a heuristic approach (Wetter et al., 2003). Wetter (2008) recommends hybrid algorithms using the General Pattern Search (GPS) method coupled with the HookeeJeeves algorithm with multiple starting points or the Particle Swarm Optimization (PSO) algorithm. Using this algorithm in GenOpt, with Energyplus output as input of the optimization problem, can be found to answer issue.

As previously noted, the objective function of this issue is the total annual energy consumption which is minimized by determining the coefficients for the efficiency and production cost of the energy. The above issue is optimized and analyzed for two efficiency, compression cooling system and evaporative cooling system in Tehran climate.

RESULTS

Order to determine and Analyzed the optimum dimensions of the window at the four main directions, for 8 types of glass studied by using either compression or evaporative cooling system, after performing optimization for 64-state results were as follows. **Figures 2, 3, 4 and 5** show the optimal window area respectively for the North, South, East and West orientations, for evaporative cooling system in comparison with compression cooling system. As can be seen, the use of evaporative cooling system in the same condition the optimum window size will be larger in all four directions. According to **Figure 2**, in the north, reflective double glass in both cases is an option and its size in evaporative cooling system is $4.5\times2.25\ m^2$ (47% of surface) and in compression cooling system is $4\times2\ m^2$ (37% of surface). As shown in **Figure 3** in the south, reflective double glass is the best and its optimum size in evaporative cooling system is $5\times2.5\ m^2$ (58% of surface) and in compression cooling system is $4.31\times2.15\ m^2$ (43% of surface).

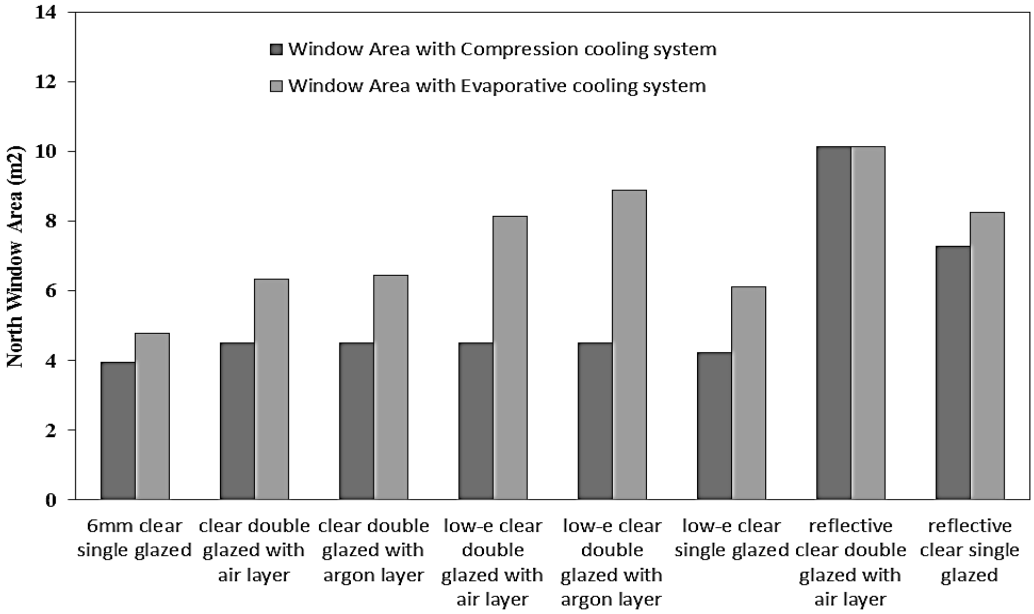

Figure 2 *Comparison of optimal window sizes for eight types in North, for systems, evaporative cooling and compression cooling*

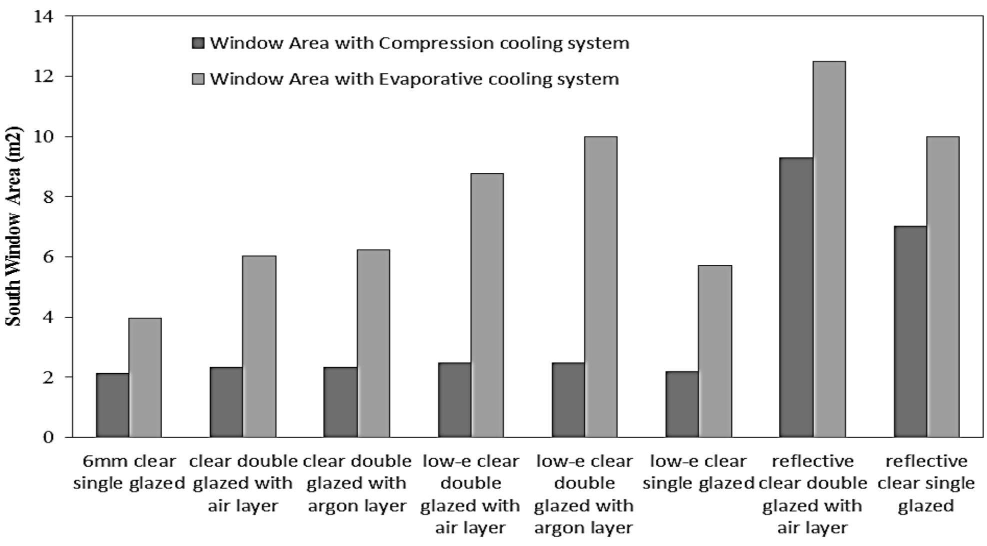

Figure 3 *Comparison of optimal window sizes for eight types in South, for systems, evaporative cooling and compression cooling*

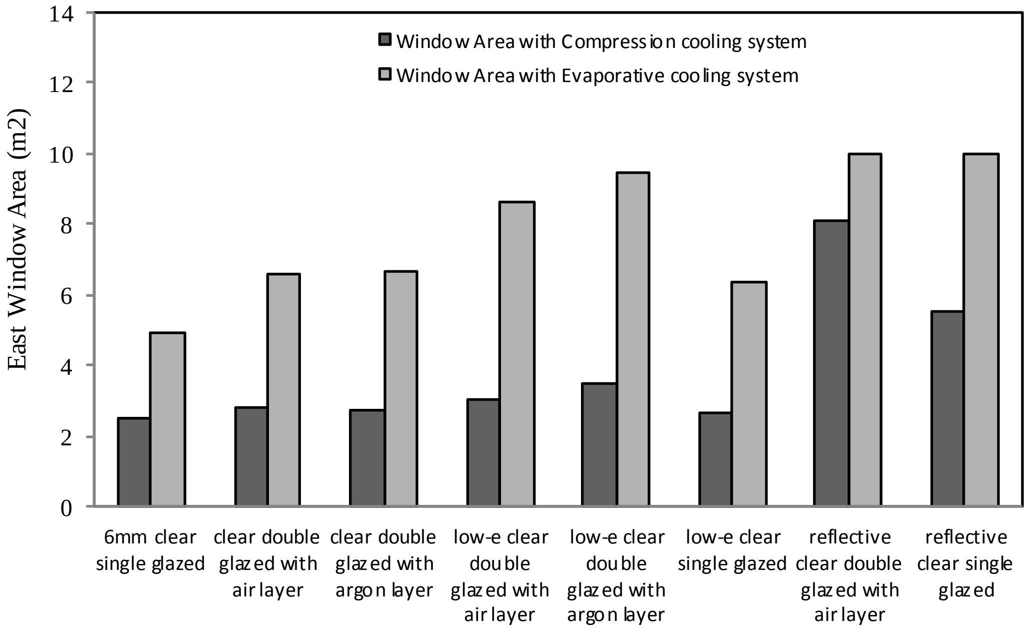

Figure 4 *Comparison of optimal window sizes for eight types in East, for systems, evaporative cooling and compression cooling*

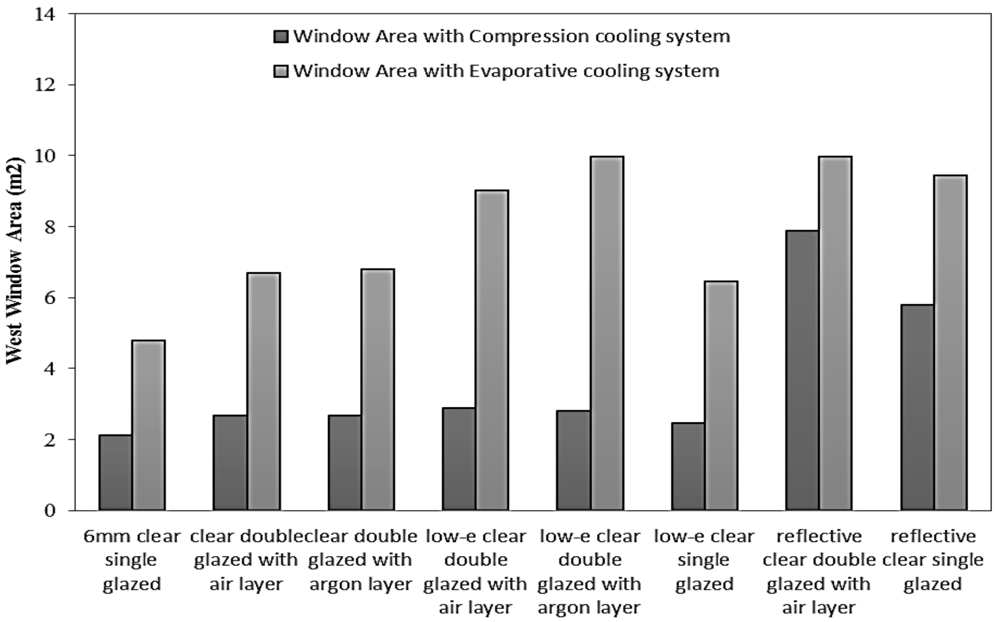

Figure 5 *Comparison of optimal window sizes for eight types in West, for systems, evaporative cooling and compression cooling*

Data in **Figure 4** indicate that East is a good choice for reflective double glass and the dimensions of evaporative cooling system is 2.23×4.46 m^2 (46% surface) and of compression cooling system is 4×2 m^2 (37% of surface). As well as shown in **Figure 5** in west direction, If using compression cooling system reflective double glass, and if using evaporative cooling system Low-emissivity double glass with argon layer and reflective double glass are better choice and Their dimensions are respectively 1.98 × 3.96 m^2 (36% surface) in compression cooling system and 2.23 × 4.46 m^2 (46% surface) for both glasses in evaporative cooling system.

The **Figure 6** shows that the optimum surface area for eight types of glass windows in the four cardinal directions, by using Evaporative cooling system instead of compression cooling system, increases in various glasses from 13 to 300 percent. As seen in **Figure 6**, using an evaporative cooling system the window size can be significantly increased with the objective to minimize the energy consumption. Among this low-emissivity double glass with argon layer with more than 300% increase in the south had the highest and reflective double glass with air layer with up to 34%, had the lowest increase. This difference is due to the Low-emissivity double glass is greater than reflective double glass amount of solar energy.

Also, **Figures 7 and 8** show the window optimum area for eight types of glasses in four different directions with each of the desired cooling system. It is observed that with evaporative cooling system, the optimum amount of window area in the south is higher than the other main directions and the area of reflective Double glazed window in both systems is higher than the other window.

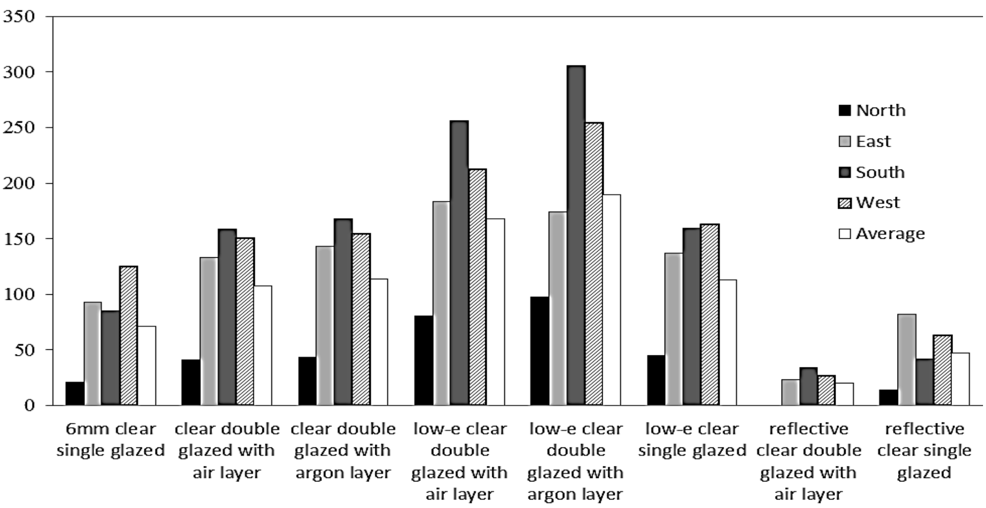

Figure 6 *Percent increase in the optimal value of the window area for eight types in four directions, for use of the evaporative cooling system for comparing compression cooling system*

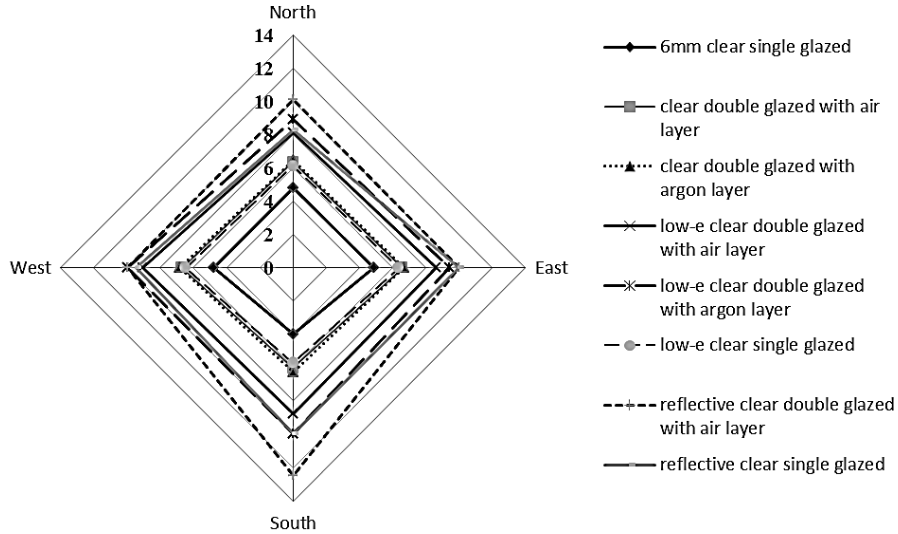

Figure 7 *The optimal value of the window for the evaporative cooling system efficiency*

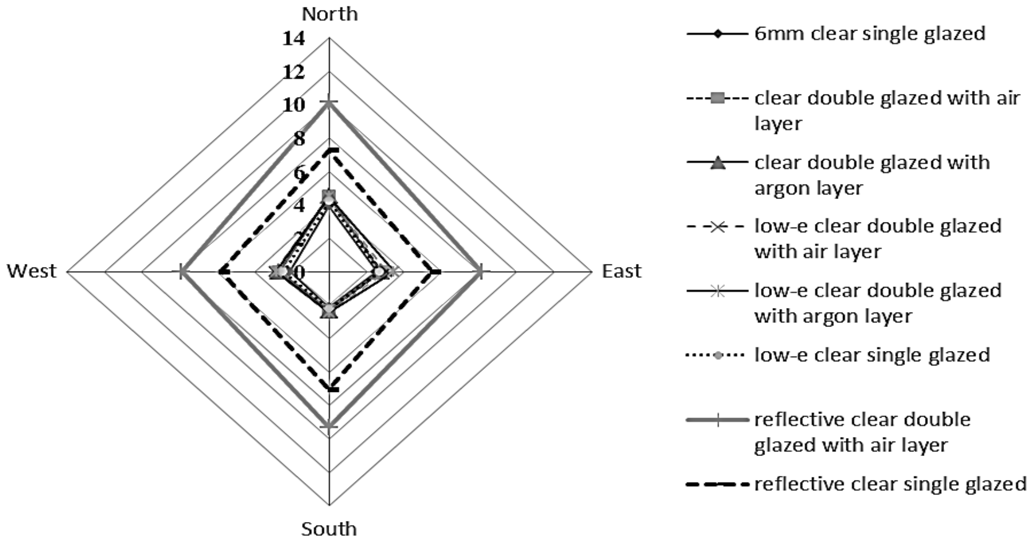

Figure 8 *The optimal value of the window for the compression cooling system efficiency*

DISCUSSION AND CONCLUSION

In this study, the effects of location, material and size of the windows were investigated in order to minimize the annual energy consumption of administrative units with emphasis on the effect of fenestration surface. The results indicate that using the evaporative cooling system compared to compression cooling system is more appropriate and more economical in Tehran climate and if office window has been placed in the optimum orientation, glass area can allocate up to 50% of façade surface. Also, reflective double glass and low-e double glazed with argon layer glass are appropriate for Tehran office building units and can respectively allocate the maximum level of window area and the minimum of energy consumption. Moreover, in the same conditions, using the evaporative cooling system, window optimum size in the four main directions can be varied from 19% for single-glazed window to 58% for reflective double-glazed window in the South direction.

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Reversible constructive system for environmentally sensitive and energy efficient schools in different climate conditions

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ABSTRACT

This research aims to develop a dry assembly, easy to build, flexible and reversible constructive system for the building of energy efficient (temporary) schools located in different climate conditions. With the intent to build schools characterized by good spatial and technological quality, high level of indoor comfort and low energy consumption it was necessary to develop an extremely simple (but at the same time extremely versatile) constructive system, able to easily adapt to different design, environmental and energy strategies. The developed system uses cross laminated timber and other natural materials and consists of small and light modular elements that can be quickly assembled according to different configurations.

Spatial-functional, technological-constructive and energy-environmental performance of the developed system have been evaluated, tested and optimized in an intense "try and test" phase in different climate zones: cold (Helsinki, Finland), temperate (Rome, Italy) and hot (Nairobi, Kenya).

In particular, the spatial-functional quality was evaluated by the application of the system in several different design configurations of kindergartens optimized with respect to following parameters: type of teaching activity, age and needs of users, spaces functionality and flexibility, paths and relationships between different (indoor and outdoor) spaces and multifunctionality of the common areas.

In relation to technological-constructive performance particular emphasis has been given to: rapidity and simplicity of assembly of building elements, expandability and modifiability of the building in response to the changing needs, cost and simplicity of maintenance over time and use of natural and low environmental impact materials.

To reduce the annual energy consumption (for heating, cooling and lighting) different active and passive environmental strategies and devices have been developed for the three different chosen climatic zones. The level of hydrothermal, acoustic and visual indoor comfort has been evaluated and quantified with the support of thermodynamic simulations and the annual energy demand was also calculated and optimized trough appropriate software.

In conclusion, tests (design application and simulations) conducted in this research have shown that the developed reversible constructive system (applicable in temporary schools) combines good spatial-functional and technological-constructive qualities with a high level of indoor comfort and a low energy consumption. Moreover, the system resulted extremely efficient also in very different climatic conditions, thanks to its easy adaptability to different configurations and strategies.

INTRODUCTION

Building - high quality and low energy consumption - schools (particularly kindergartens) are a priority of the many governments in the world. In Italy, e.g., more than 50% of school buildings do not correspond to current spatial, functional, energy and seismic standards and urgently need to be renovated, expanded or replaced. In some regions of Germany it is an urgent need to build many kindergartens to ensure every child a place to spend the day while its parents work. Even in most developing countries (Africa and Southeast Asia) the humanitarian interventions are focusing their field of action on the creation of schools: e.g. Zambia needs immediately 10,000 classrooms. Moreover, in many countries, there is also the need to provide temporary school buildings (quickly realizable and totally removable) to be used after natural disasters or during the redevelopment of existing schools.
Furthermore, an investigation carried out a few years ago by the U.S. Green Building Council (USGBC) has estimated that in the U.S. "*more than 55 million students spend hours every day in buildings with poor ventilation, inadequate lighting, inferior acoustics and antiquated heating systems*" (www.usgbc.org). Because of this, USGBC started a study called "Greening America's Schools - Costs and benefits" which concluded that *"Greening school design provides an extraordinary cost-effective way to enhance student learning, reduce health and operational costs and, ultimately, increase school quality and competitiveness"* (Kat, 2006). Based on these research results and with the aim of promoting the development of energy-efficient schools, 2006, USGBC launched LEED for schools. These new suite of rating systems recognizes the unique nature and educational aspects of the design and construction of schools. Also the U.S. Department of Energy has promoted a program called *"EnergySmart Schools"* that shares "*best practice and technologies for achieving significant savings in both new construction and school renovation*". This program also provides tools and training for school planning, financing, operation & maintenance, and energy education. Moreover, the ASHRAE has just published an *"Advanced Energy Design Guide for K-12 School Buildings"*.

OBJECTIVES AND METHODOLOGY

On the basis of the above considerations this research aims to develop an easy to build, flexible and reversible constructive system for the building of high spatial-functional quality, good technological-constructive standard and excellent energy efficient school buildings located in different climates. The idea of designing buildings in different climatic conditions was born from a faculty exchange between UNICAM, Italy and Cal Poly, USA in which 2nd year architecture students have been involved in the design of energy-efficient school buildings located in different climatic zones in Italy and in USA (Rossi, 2012). Based on this very positive didactic experience it was decided to accept "the challenge" of designing in different climatic conditions also for this research, particularly for the design of a very versatile constructive system.

To achieve this goal, the research has been organized into the following phases:

1) Detailed analysis of: A) spatial, functional, energy and seismic standards for school buildings in different countries, B) types of learning and teaching and their impact on the design of the spaces, C) materials and constructive systems with lower environmental impact and suitable for use in reversible processes, D) Climatic conditions and indoor comfort standards in three cities chosen as case studies, E) passive and active energy strategies and devices efficient in different climate.
2) Development of a constructive system in cross laminated timber.
3) "Try and test" of the spatial-functional, technological-constructive and energy-environmental performance of the developed constructive system in different climate through appropriate tools.
4) Optimization of the constructive system on the basis of the results of the "try and test" phase and development of the final system.
5) Application of the system in 3 case studies: Helsinki-Finland, Rome-Italy and Nairobi-Kenya.
6) Evaluation of results of applications.

DEVELOPMENT OF A CONSTRUCTIVE SYSTEM FOR SCHOOL BUILDINGS

With the intent to develop a constructive system for the building of energy efficient (temporary) schools located in different climatic conditions, particular importance has been given to achieving a high level in three categories of performance: spatial-functional, technological-constructive and energy-environmental. In this paper, for reasons of space and in relation to the topics of the conference, more emphasis is given to the last one.

Spatial-functional performance

In school buildings the type of teaching and the specific needs strongly influence the spatial-functional aspects (Dudek, 2007). At the same time the architecture (as consequence of the spatial-functional choices) plays an extremely important role: it houses not only the spaces in which it is possible to perform a certain function but, if well and smartly designed, it is able to improve the way and the efficiency in performing this function. The Dutch architect Herman Hertzberger, who has more than 50 years experience in design and construction of all kinds of school buildings, believes that in school buildings "*architects should […] create spatial conditions that will benefit learning in general sense. The building should provide a general framework for education and learning, while being flexible enough to respond to changing demands […]. Schools are where you can withdraw and adopt a position with respect to others, where you learn to assume a place in society*".

Because of this, kindergartens designed in this research aim to be designed "as a city" and at the same time "as a home" (Hertzberger, 2009). "As a city": with public and private spaces, "squares" to meet other students, enough playgrounds, visual links and a "streets" system. "As a home": where children don't feel lost and have a sense of security. Between the many possible spatial-functional configurations, three (based on different teaching concepts and adequate to the different climatic conditions typical for the specific case study) are chosen: 1) *compact*: with a big indoor collective space as middle point and short connection ways between the different rooms, suitable for an "open concept" of kindergarten, where kids of different ages are free to move between the various spaces - recommended for cold climate; 2) *linear*: with a bigger distance between the different rooms and more open to the outdoor space, suitable for a "classical concept" of kindergarten, where kids of different ages play in different rooms - recommended for temperate climate; 3) *courtyard:* with a big covered outdoor collective space as middle point, suitable for a "outdoor concept" of kindergarten, where kids spend a lot of time a day outdoor - recommended for hot climate (see fig. 1).

All configurations include some standard spaces (see caption of fig. 1) characterized by a careful study of surface color - which can be aggregated in different ways, based on different teaching concepts or climate conditions.

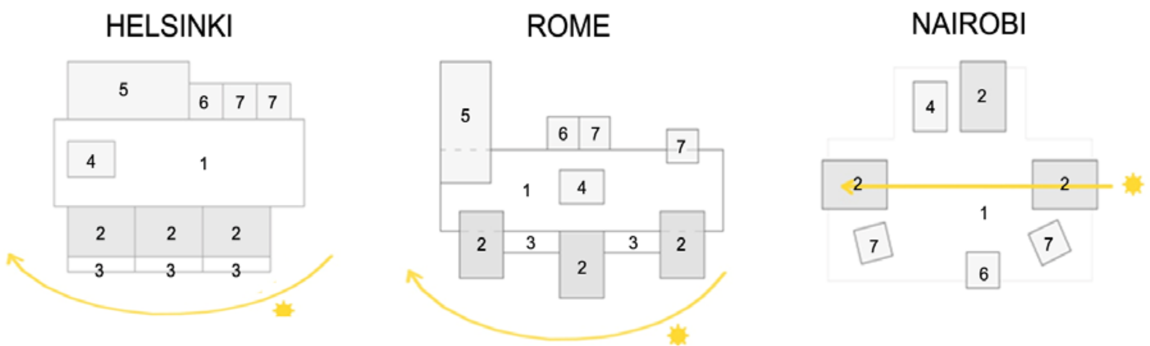

Figure 1 Three possible spaces configurations for the three studied sample schools. Legend: 1 (internal or external) collective space, 2 classrooms also containing bathrooms for children, 3 solar greenhouses that can be also used as porches, 4 bathrooms for faculty and staff, 5 big multifunctional space (canteen / collective play room), 6 technical room, 7 offices.

Technological-constructive performance

Requirements that have greatly influenced the development of the constructive system are:

a) Reversibility of the system for the use in temporary buildings: dry-assembly technology.

b) Application of the same modular and versatile easy-to-build elements in different configurations.

c) Use of low environmental impact components: natural and recyclable materials.

With regard to this last requirement, it is not possible to identify materials or construction systems that have a low environmental impact in so many different climatic zones (culture and economies). In order to preserve the original idea of the research to *"design in different climatic zones with the same constructive system"*, but inevitably at the expense of low environmental impact in some climates, it was decided to use natural materials such as wood. This material has a good relationship between cost and environmental impact in cold climates (e.g. in Finland wood is a traditional building material) and in temperate climates (e.g. in Italy the government is trying to promote the use of wood from environmentally sustainable plantations as building material), while it is less eco-friendly in hot areas such as in Africa. Here the developed constructive system could be realized with local wood or other local natural materials. Being the building single-storey, materials with particularly high structural features are not required. Based on the above considerations, it was decided to use beams and pillars of laminated wood (Gutdeutsch,1996) for the big collective space (not provided in the African application) and cross laminated timber wall- and ceiling-panels (Lehmann, 2012) for the rest of the building (e.g. classrooms, bathrooms and offices, which are designed as prefabricated boxes). The outside wall covering is made of painted wooden slats, while the thermal insulation is in wood wool or pressed cellulose. Structural elements are identical in the different possible design configurations, while the layers of the building envelope (in particular thickness and materials of thermal insulation) change in the different climatic zones in order to improve the energy-environmental performance. Sizing of modular elements (easy movable by one to three not specialized people), construction details and assembly systems (see fig. 2) have been developed in close cooperation with Italian manufacturers of wood components. This collaboration has allowed evaluating feasibility and costs.

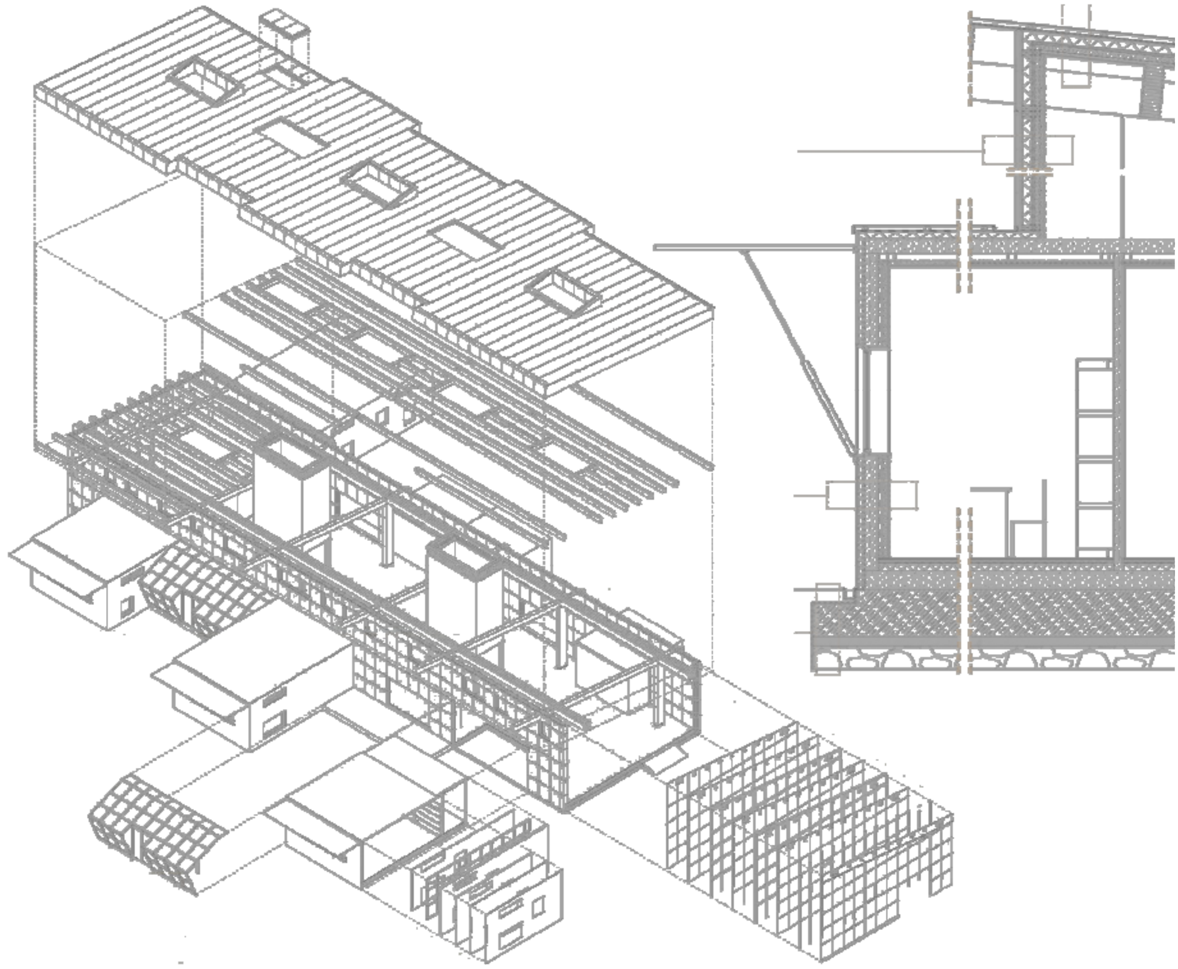

Figure 2 Project proposal for Rome: exploded isometric and detail section of a classroom.

Energy-environmental performance

The achievement of high energy-environmental performance has been the main objective in the development of the construction system and in the design of its possible applications in kindergartens located in different climatic conditions. The most difficult challenge has been to design *one* constructive system and *many* design solutions able to meet requirements sometimes contradictory to each other: 1) design a very flexible system: elements should be as *"neutral"* as possible, in order to work well in any design configuration, 2) application of the constructive system in low energy consumption and high comfort buildings: design and technological solutions should be *"specific"* and calibrated on the basis of different local climate (Ford, 2007) and users needs. The search for balance between "neutral elements" and "specific design solutions" has led to a long “try and test” phase finalized to reach an energy balance optimization understood as result of double simultaneous adaptations: the one dedicated to energy needs based on climate condition and the one dedicated to the environmental comfort for users. So building elements, in particular facades, have been conceived as three layered element: an external cladding, a middle “control” layer (dedicate to modulate thermal and moisture fluxes through the whole building surface) and an inner structure (a mechanically more rigid part of the wall). This design methodology is inspired from the research “The Perfect Wall” carried out by Joseph W. Lstiburek (Lstiburek, 2008).

With the intent to achieve high energy-environmental performance, this research aims to develop not only the elements composing the constructive system, but also the "assembly method" and the relations of these elements. This "assembly method" involves the use of (active and passive) strategies and devices for the improvement of the environmental control. As strategies it means e.g. building orientation towards cardinal points and prevailing winds, surface-to-volume ratio and windows orientation. The devices are e.g. solar screens, high performance building envelopes (e.g. characterized by high thermal transmittance or high thermal inertia), ventilation chimneys, Trombe walls, solar greenhouses, photovoltaic etc.

APPLICATION IN THREE CASE STUDIES AND ENERGY EFFICIENCY VERIFICATION

With the intent to verify the spatial-functional, technological-constructive and energy-environmental performance of the developed constructive system, it has been applied in three case studies located in Helsinki Finland, Rome Italy and Nairobi Kenya.
With regard to the environmental-energy performance, accurate analyses of the local climatic conditions (temperature, rel. humidity, wind speed, direct and diffuse solar radiation etc.) were conducted with the support of the software Meteonorm (fig. 3).

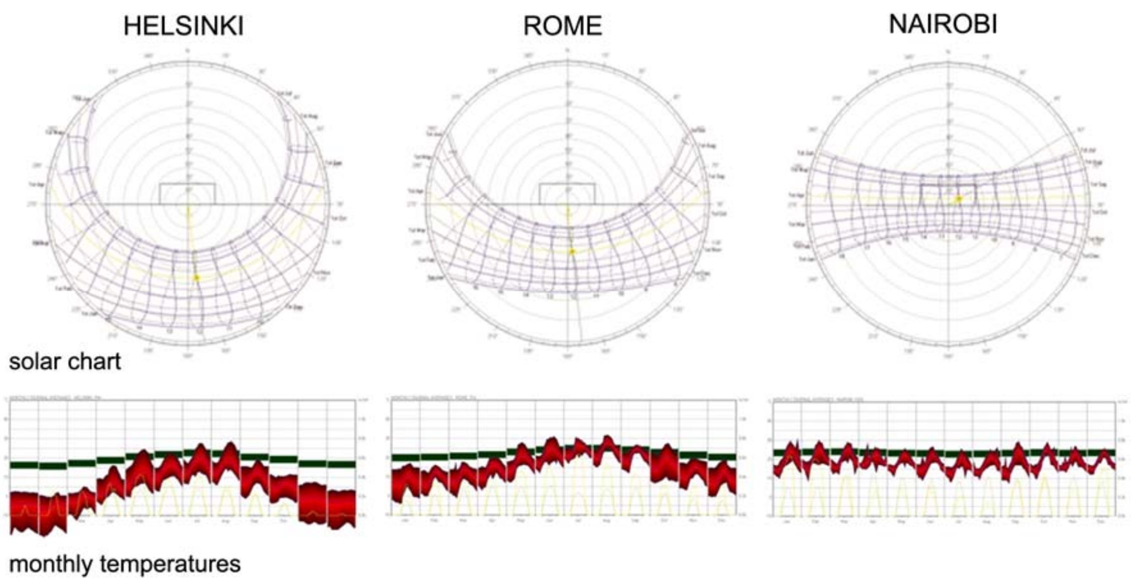

Figure 3 Example of climate data analyses: solar charts and monthly temperatures.

The climate data were the basis for the elaboration of psychometric charts (fig. 4), in which different design strategies and devices (thermal mass, passive solar heating, natural ventilation etc.) are verified in relation to the maximization of “users comfort zone”.

On the basis of this results, in each of the three chosen cities, appropriate strategies and devices have been developed and applied in a design project (fig. 5) that are shortly presented in the following paragraphs.

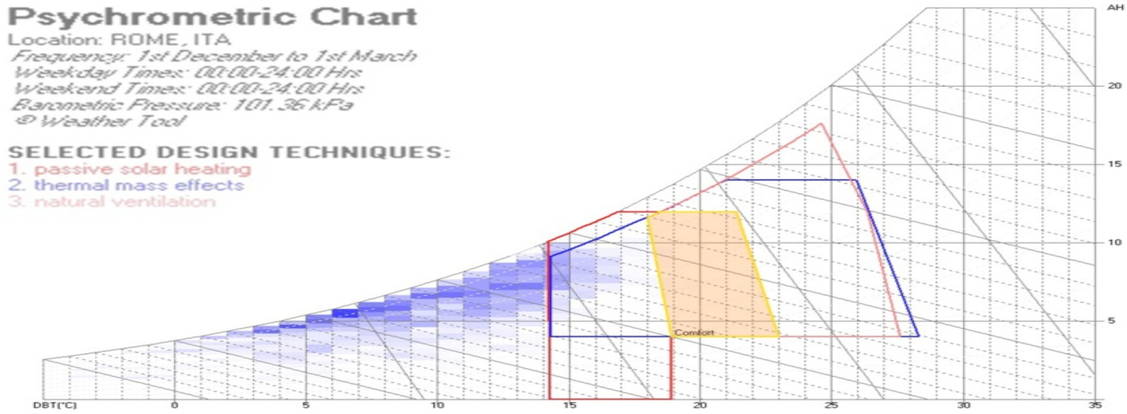

Figure 4 Example of psychometric chart with “design strategy” – Rome.

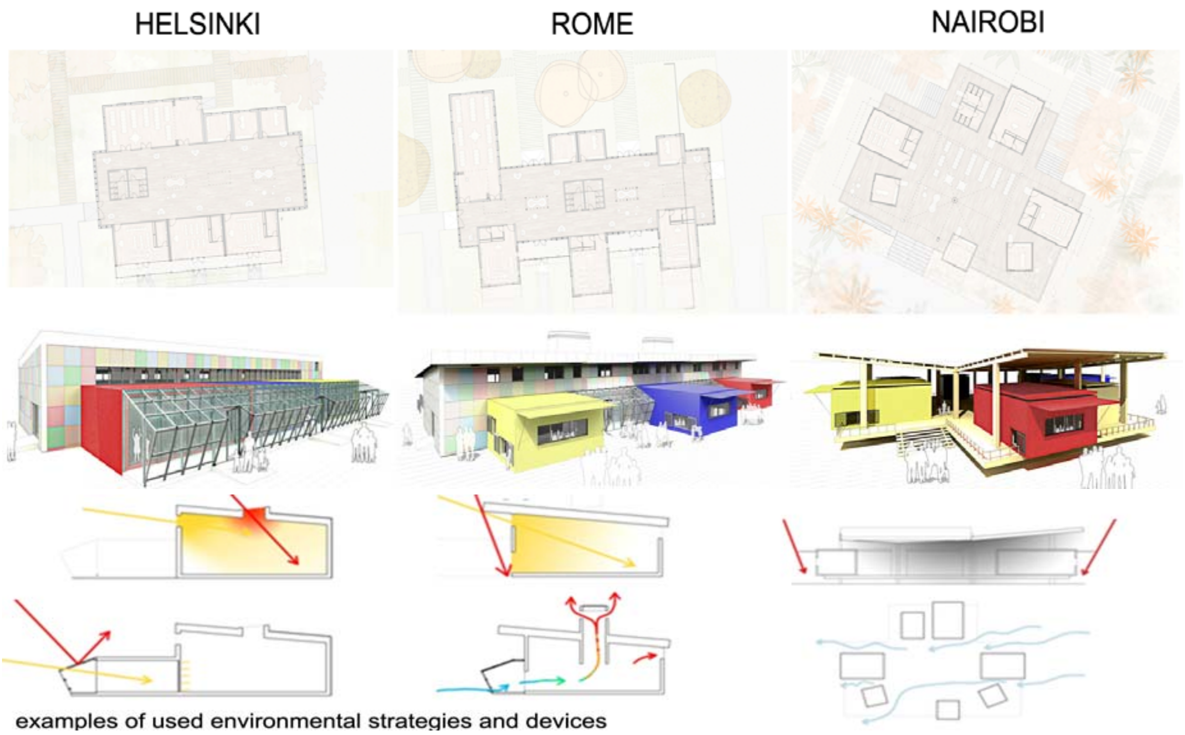

Figure 5 Design application in the three case studies and examples of used environmental strategies and devices.

Helsinki (Cold climate: winter strategies and devices)

Orientation of the building: main axis direction east-west, *S/V* = 0.56 (compact form, low thermal dispersion), *U-value Nord façade*: 0,19 W/m^{2}K (passive building) *Insulation material:* wood wool, *Window to wall ratio Nord façade:* 20% , *Window to wall ratio South façade:* 85%, *Other devices:* maximizing day lighting through windows in the roof and in the south side, efficient solar greenhouses, heating system (see figure 5).

Rome (Temperate climate: winter and summer strategies and devices)

Orientation of the building: main axis direction east-west, *S/V* = 0.63 (articulated form, medium thermal dispersion), *U-value Nord façade*: 0,35 W/m^{2}K (compatible with the Italian regulation) *Insulation material:* wood wool and pressed cellulose, *Window to wall ratio Nord façade: 30%*, *Window to wall ratio South façade:* 50% in winter and 35% in summer, *Other devices:* building envelope characterized by a high thermal mass M_s = 230kg, high thermal inertia Y_{ie} = periodical thermal transmittance = 0,10 W/m^{2}K , windows and solar screens suited to maximize day lighting and solar gains in winter and to minimize them in the summer, solar greenhouses in winter / porches in summer, passive cooling through stack and cross ventilation optimized for the specific climatic conditions, evaporative cooling, heating and cooling system (see figure 5) (Beckera et al., 2007; Filippin et al, 2007).

Nairobi (Hot climate: summer strategies and devices)

Orientation of the building: square plan around a outdoor covered collective space, *S/V* = 1.12 (permeable form), *U-value façades*: no thermal insulation, only acoustic insulation exclusively for classrooms (pressed cellulose or local materials), *Window to wall ratio:* ca. 35%, different for different orientation. *Other devices:* building raised above the ground separated volumes and raised roofs to maximize natural cross and stack ventilation, high heat loss common areas outside under a large cover that shields even the buildings below, no heating and cooling system (see figure 5).

The energy efficiency of these design choices has been quantified through a set of affordable design tools like: thermo K8 (a common practice used software for the analysis of thermal performance of multi-layered single constructive elements), Heat (to proof thermal bridges) and Autodesk Ecotect (a dynamic simulation model managing each thermal zone in an inter-zonal calculation process to evaluate the comfort level and to calculate the energy demand during the time). The energy performance is quantified under static and dynamic conditions and is verified (if possible) in relation to the regulation of the three different chosen countries (particularly Finland and Italy).

The analyzed parameters are:

- For the single constructive elements (particularly façades): U-value, superficial mass, thermal lag , decrement factor, periodical thermal transmittance, vapor diffusion resistance and air permeance (based on recursive-steady state calculation Glaser method).
- For the single rooms. Classrooms: thermal hydrometrical comfort - PMV, acoustic comfort, day lighting and lighting comfort on the floor and on the work level. Greenhouses: annual passive solar gain.
- For the whole building: annual energy demand for heating, cooling and lighting, annual passive solar gain in cold climate and in temperate climate in winter (see figure 6).

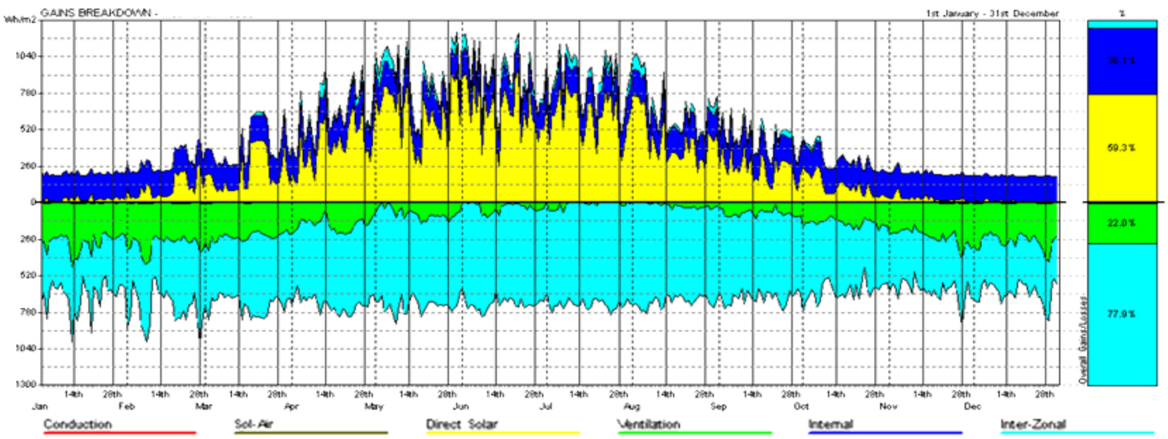

Figure 6 Annual passive solar gain - case study Helsinki.

From an energy simulation point of view the results consider thermal comfort range of 5°C temperature swing an 10% relative air humidity as a driver for air-mass-envelope exchange of sensible and latent heat according the idea of minimize, or exclude the role of HVAC facilities during three seasonal condition (spring autumn and winter). Even if the results of building simulations can be simplified it takes in account a sensible reduction in monthly degree day for heating and cooling according the energy saving methods in the three climate conditions. This acts as a whole building design considering alternative design solutions in a didactic perspective for students as a possible experimental platform to better improving cost, comfort and energy efficiency standards.

Simulations were not carried out after the project end but as very important part of a optimization recursive design process. Indeed, this "open-solution model generator" approach typical for the used software (in particular Ecotect) is a simple design methodology for the designer (e.g. architects) to control the different results and influences of a particular design solution (e.g. building shape or assembly method), air change rate, occupation, internal loads etc. to internal comfort level, energy demand and energy balance of the entire building. With the intent to minimize the use of active systems, passive solar analyses (fig. 6) are one of the most interesting intermediate results of this research for the appropriate use of devices like greenhouses, evaporative cooling etc.

All the simulations carried out in the three case studies have shown a high level of environmental comfort and an extremely small internal energy demand for heating, cooling and lighting in relation to the climatic zone. Kindergartens designed in Helsinki and Rome achieve the standard “near to zero energy building” (with the use of passive devices and active systems like photovoltaic and solar collectors). Moreover, in all three buildings PMV has values between -1 and +1 even in periods with extreme climatic conditions (Helsinki in winter or Nairobi in summer).

CONCLUSION

In conclusion, tests (design application, static and dynamic simulation) conducted in this research have shown that the developed reversible constructive system (applicable in temporary schools) combines good spatial-functional and technological-constructive qualities with a high level of indoor comfort and a low energy consumption for heating, cooling and lighting. Moreover, the system resulted extremely efficient also in very different climatic conditions, thanks to its easy adaptability to different configurations and strategies.

This work was born in a school of architecture as a graduate thesis presenting an environmental research scenario for locations with peculiar climate and performance needs based on the final better judgment from the design team. From an educational operative perspective the work of comparison between different performance responses is an open-mind attitude to stimulate the research in sustainable construction methods.

The architectures' primary role is guaranteed as the method gets a lot of dedicated input information to lead in the design phase. Each information can have a particular importance in processing the ideas from a sketch or from a detailed commission request, (for example from a local government program).

The collaborative role of building physics became not abstract or simply theory, but is addressed to be an useful cooperation design technique.

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ARCHITECTURAL PROTOTYPE FOR HIGH ENERGY EFFICIENCY URBAN HOUSING IN CENTER-SOUTH CHILE.

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ABSTRACT HEADING

This applied research is to design a buildable high energy efficiency modular prototype of urban housing, able to overcome the sustainable weaknesses of housing construction in centre-south of Chile, present in all economic and social sectors. This deficiency is originated by lack of adaptability of the typical shapes and construction to environmental requirements of the local climate, resulting in serious inefficiencies in their energy performance and comfort. A building system was developed by a multidisciplinary research team, with support from representatives of the local builders and real estate market, generating highly energy-efficient homes based on the integrated design approach. The prototype allows covering diverse residential needs, considering both the build surface and the number of habitable rooms, creating scalability in time and extension. The system, called "CASA+" (Spanish acronym of "House plus", due it offers higher diversity and comfort than current designs), can arrange different settlements, to create diverse urban densities and efficient use of sunlight.

BACKGROUND AND OBJECTIVES

Residential buildings in centre-south Chile have made consistent progress in the recent decades. Most of this growth is based on detached houses, executed in repetitive groups of a reduced size, of up to 60m2, which subsequently increases spontaneously forming variable clusters with few facilities and a lack of urban cohesion. So far, the priority in Latin American's urban development has been to face the demand for basic housing, relegating, when not ignoring, the environmental problems, which has meant building inefficient homes with high energy demands, particularly significant in climates with a strong seasonal variability. In the Centre-South Chile there are specific studies that put these demands in a range between a minimum of about 110Kwh/m2 for detached houses with two floors, and a maximum of 192Kwh/m2 per year. In the simulations performed as part of the research project MEL CONICYT 81100003 (2011-2012) "Integrated Design for Energy Efficient Housing Reconstruction", the average heating energy demand of a detached house in the study area has been calculated as 143kwh/m2. This demand is fulfilled with burning combustion systems, especially in the lower class areas, combining poor fuel quality (non-certified wet wood) with low efficient equipments, resulting in poor indoor thermal conditions (with an inner average temperature of 16°C) and poor indoor air quality as a result of inadequate combustion. In the current context of strong growth of housing construction after the earthquake of 2010, and given the high price of conventional energy, reducing the energy demand has become a priority within the strategic objectives of the country's development.

The project starts from the realization of the limitations of the previous experiences, and proposes a flexible system that enables the development of energy-efficient homes with multiple possibilities for grouping and growth under different climatic and socioeconomic levels for different areas. It is solved by a modular, replicable and high customizability construction system, that increase the quick construction after an earthquake, minimizes the costs and guarantees the constructive quality of an industrial process, inside the long tradition of this tipe of architecture (Prouvé, Koening, Lods, Ehrenkrantz). The development of the system is now in the penultimate stage of the project.The earlier stages consisted of analyzing the climate and constructive problems of the study area and its architectural background. At the current stage, the foundation for the design of CASA+ has been laid (the detailed implementation plan that defines the construction of a real-scale prototype is yet to be developed). The work methodology has been the Integrated Design Process, which combines multidisciplinary participation with different points of view with a working model that predefines the goals to be achieved (qualitative and quantitative), developed in successive steps of complexity.

The specific goals have been defined in architectural aspects (minimal surfaces, grouping and integration ability), urban aspects (minimum density), economic aspects (cost range) and construction fields (modular systems and construction according to the local industry); as well as achievable goals for energy efficiency, as a minimum verifiable saving result was set to not less than 55% (category A in energy efficiency) with respect to a traditional house taken as reference.

The aim is to rethink the characteristics of traditional Chilean housing, consisting of a two floors house typology, with a length-width ratio of 2 to 1 and gabled roof, usually arranged isolated or paired, and with surfaces ranging from 36m2 (low income housing) to 90m2. In the middle or lower-middle class subsidized housing sector, the surface and number of bedrooms is very similar to the prototype of 60m2. (Fig.1). Extensions in upper modules, with a third floor or living space under the roof, can raise the prototype's surface up to 90m2 with four habitable rooms. It is also possible to extend the modulation by the sides, increasing the surface area due to the modular nature of the proposal. The multiplicity of grouping possibilities from the same unit can generate many different neighborhoods and densities, along with material and surface characteristics of housing and the plot's size without sacrificing the basic qualities of spatial quality and energy efficiency of basic housing (Fig.2).

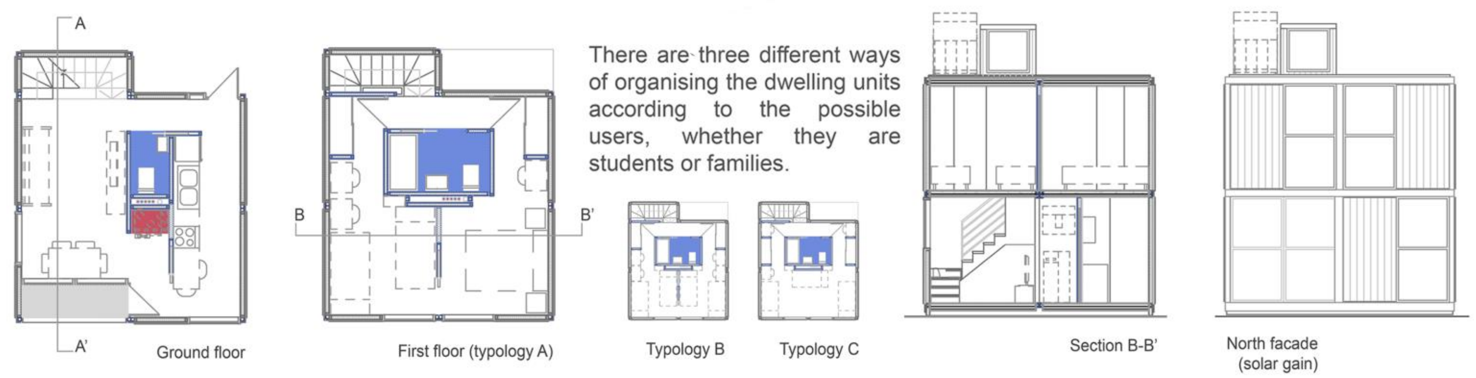

Figure 1. Architectural definition of the 60m2 prototype.

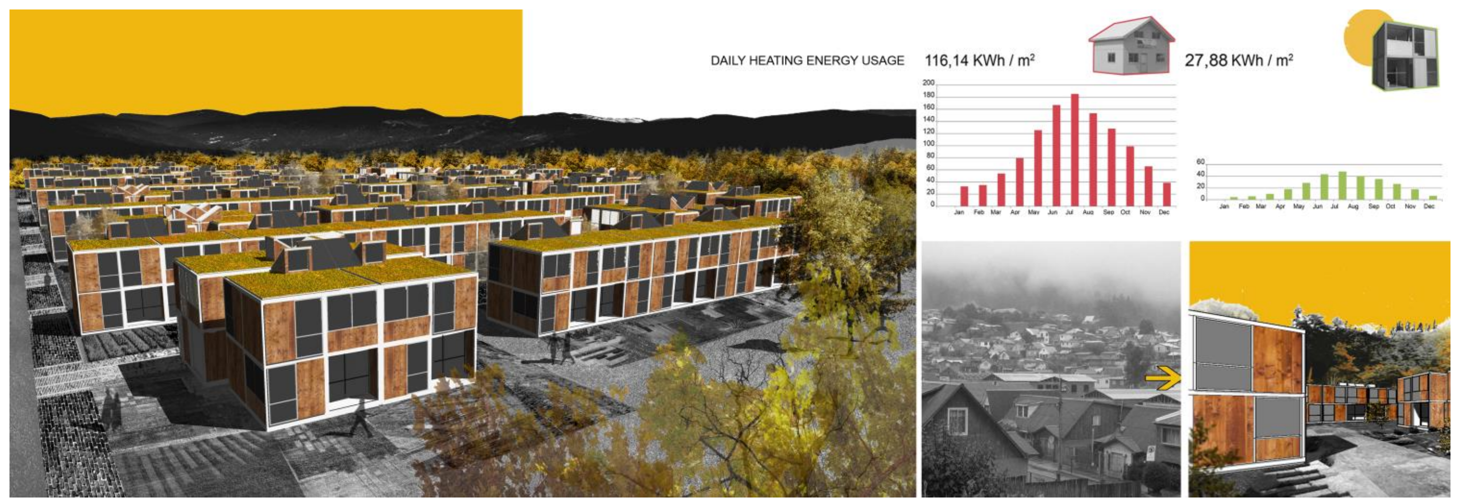

Figure 2. Example of neighborhood using the prototype. It changes the traditional system of grouping houses and improves the energy efficiency as well.

DESIGN STRATEGIES

CASA+ should be understood as a system design, a set of architectural and constructive elements that with different possibilities for clustering on each scale result in diverse architectural and urban solutions having in common a significant improvement in energy efficiency with respect to a conventional home of the same size. It combines a number of solutions adapted to different architectural scales, considering different environmental stresses taken from the detailed climatic analysis carried out during the development of the MEL research.

In the geographical scope of the study, the analyses show needs for energy input (heating) in winter, sun protection and natural ventilation in summer (no need for cooling) and a need for reducing humidity throughout the year. The bioclimatic diagrams for Concepcion's area shows that there are long periods of the year (winter, spring and fall) where the passive solar contribution would be sufficient to reach the comfort zone, requiring only some heating input at some specific periods (Fig.3).

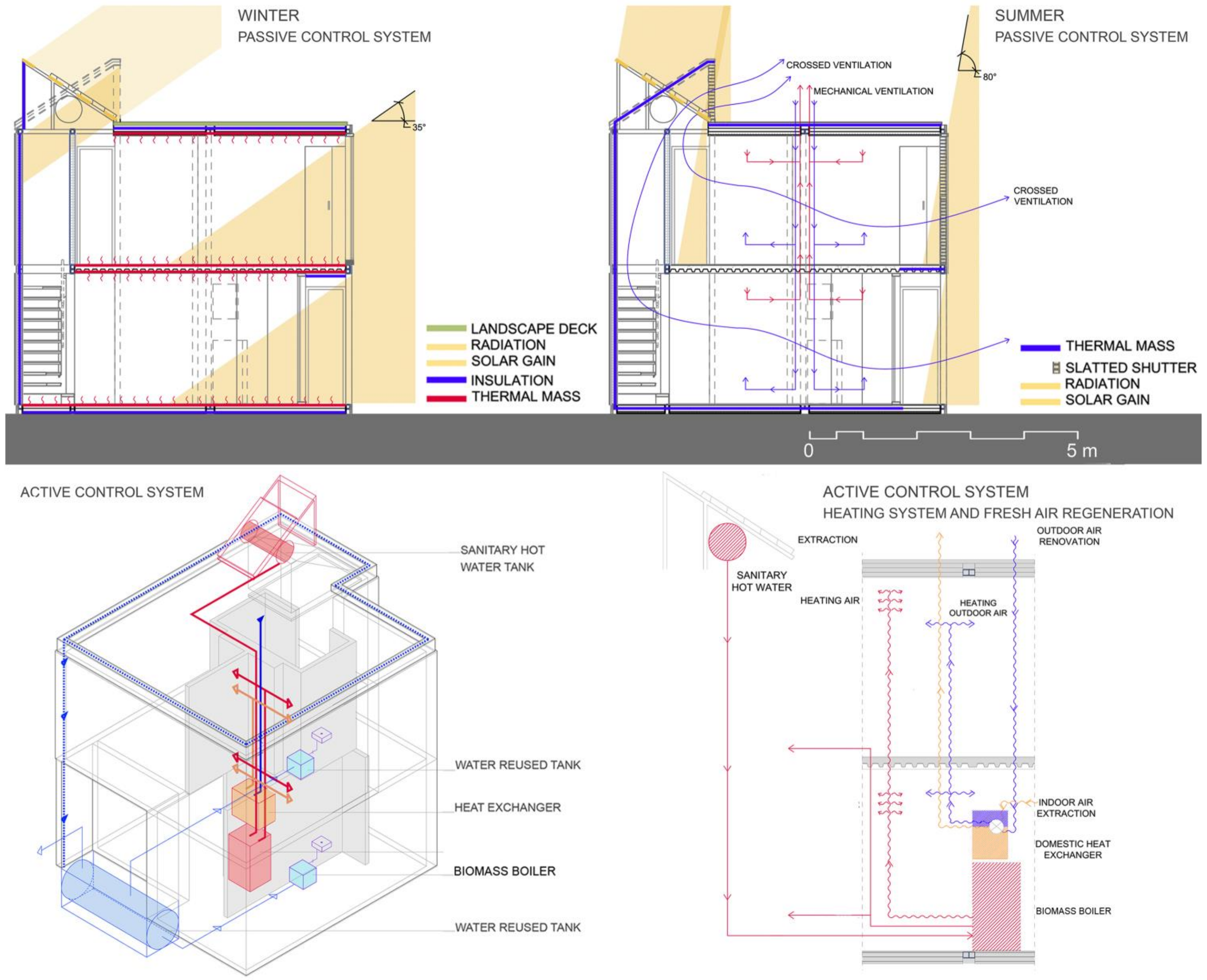

Figure 3. Passive and active climatic control systems of the prototype.

The following design strategies to consider in the prototype depending on the environmental requirements defined in the climate diagrams of reference:

- The strategies to reduce the thermal losses, as the decrease of the envelope area by compact units with a small form factor and by aggregations of more units (detached homes, attached or block). To do this, CASA + adopts a structure based on cubic forms, thus reducing significantly the form factor, with a relationship surface/volume of 0.75 (the area by reference is the sphere, 0.60). When compared to a traditional house with the same area, usually prismatic, CASA+ reduces the exposed surface by 20%. The prefabricated panel system with inner insulation, implying a U factor of 0.37 W/m2K and 0.31 W/m2K for walls floors and roofs. The windows, using double glazing with low emissivity, are a U value of 2.41 W/m2K, and the improvement of the transmission coefficient in joinery, using systems of thermal break.

- The strategies to increase the profits are the well-orientation house and windows for solar gains (CASA+ orientates one main facade to north +/- 45°, where all living spaces are placed). The correct dimensioning of windows in the north facade between 60% to 75% of the facade's surface, which represents between 20 and 30% of the floor surface, as recommended by simulation programs. Also the prototype improves a heating system's of high efficiency, using a combustion system of a biomass boiler of pellets. Finally, thermal inertia is incorporated in interior walls and decks.

- The strategies to improve the ventilation and infiltration rates, is an important point due to the high relative humidity rate in the study area (around 70%). CASA+ introduces a system of natural cross-ventilation through the opening of windows on the roof, and introduces enthalpy exchangers with double function, forced ventilation and heat recovery. A suitable infiltration rate to be achieved is 1ach, which implies a more airtight construction (manageable by the local industry), through proper sealing joints between panels and facade cover, and between them and the window frames.

- The strategies to reduce the solar insulation in summer (although extreme heat conditions are not climatically significant in the study area) in highly exposed north facades during the summer (even more with the high amount of window's surface), are the use of setbacks on facades to generate shadow.

ARCHITECTURAL DESIGN AND CONSTRUCTION SYSTEM

The building systems used in the traditional construction are variable, but the most common consists of a first story made of masonry confined in a concrete structure and a second story with a gabled roof made of timber framework with enclosures made of wood panels. The thermal behavior of traditional housing is a consequence of the construction system, which follows the established legal rules. The location and placement of the housing plots follows an economic criterion (filling all the available space) rather than a rational study of local climatic factors (orientation, sunlight, obstruction).

The prototype attends, however, to a global concept of sustainability, which involves not only the improvement of the comfort conditions (compared to traditional housing) through improved building systems, but also through a correct formalization and orientation of the dwellings in the urban context. The improvement of the form factor intervene in this point, as it implies a better relationship between volume and surface area, and is complemented with a modular construction system, based on a sandwich panel SIP, with a modulation of 2.45 m x 1.225 m, which can be placed either vertically or horizontally. They conform cubic units to the addition of a structural framework, establish the basic unit in modules of 2.67m x 2.67m. The plan of CASA+ is arranged with the junction of 4 units, generating a square of 5.34 m. side and 28.5 m2 of floor area. The basic house, with two levels, is then defined by an area of 57m2, to which the staircase module is added. This element is conformed as one piece attached to the cubic structure in the opaque facade, generating a total area of 60m2 and 53.5 m2 of floor area.

As a result of the contact with companies of the construction sector in the study region, it has been decided to use a mixed construction system that combines elements that may either be manufactured in a workshop or industrialized (such as cladding panels and decks), with uncomplicated assembly work (Fig.4). The materiality of the finishes, enclosure systems and decks can be easily exchanged, leading to multiple aesthetic choices. The constructive system consists of a structural system, an enclosure and a facilities system. The facades are solved by a wood sandwich SIP panel with EPS insulation 100mm thick. These elements may or may not be coated on their inner sides, while the outer face comprises a waterproof treatment and may be coated with a waterproof and breathable membrane. The finish is a ventilated facade system of lightweight concrete 10mm thick. The outer panels are directly fixed to the structure, formed by a framework of beams and pillars that define a cubic cage, which can be done in steel, solid or laminated wood, and can come directly manufactured or prepared to be assembled on site using screws and pins. Diagonal bracing ensure vertical stability, while the horizontal stability is stiffened by the slabs. The foundation can be done on site with ditches, or come prefabricated as concrete blocks. The slabs, in the basic proposal, are made of concrete with steel decking 0.75mm thick that can be performed on site or come prefabricated from the workshop. However, since in some climatic regions studied, the difference day-night temperature is not very significant, they could be replaced by lighter elements such as the same SIP sandwich panels used in the facades but with a higher thickness (150mm.). The roof is defined by the same deck, incorporating a landscape deck. The staircase is considered as a prefabricated separate element.

The bathroom and kitchen facilities can be performed either in a traditional way or come prefabricated from the workshop. The lower floor's wet unit, where kitchen and toilet are grouped, and where an air conditioning indoor unit could be placed, can be done industrially, including furnishings and appliances, and then be assembled in the working place. The climate control system is designed to support a unit of biomass considered carbon neutral, located at the center of the house. Given the need for ventilation due to the humid climate (1 ach), the climate control system is supported by a system of heat recovery located in the forced renewal unit. Natural cross ventilation is established between the lower floors and the skylight located over the stairway. Supports for solar or photovoltaic energy are installed on the flat roof.

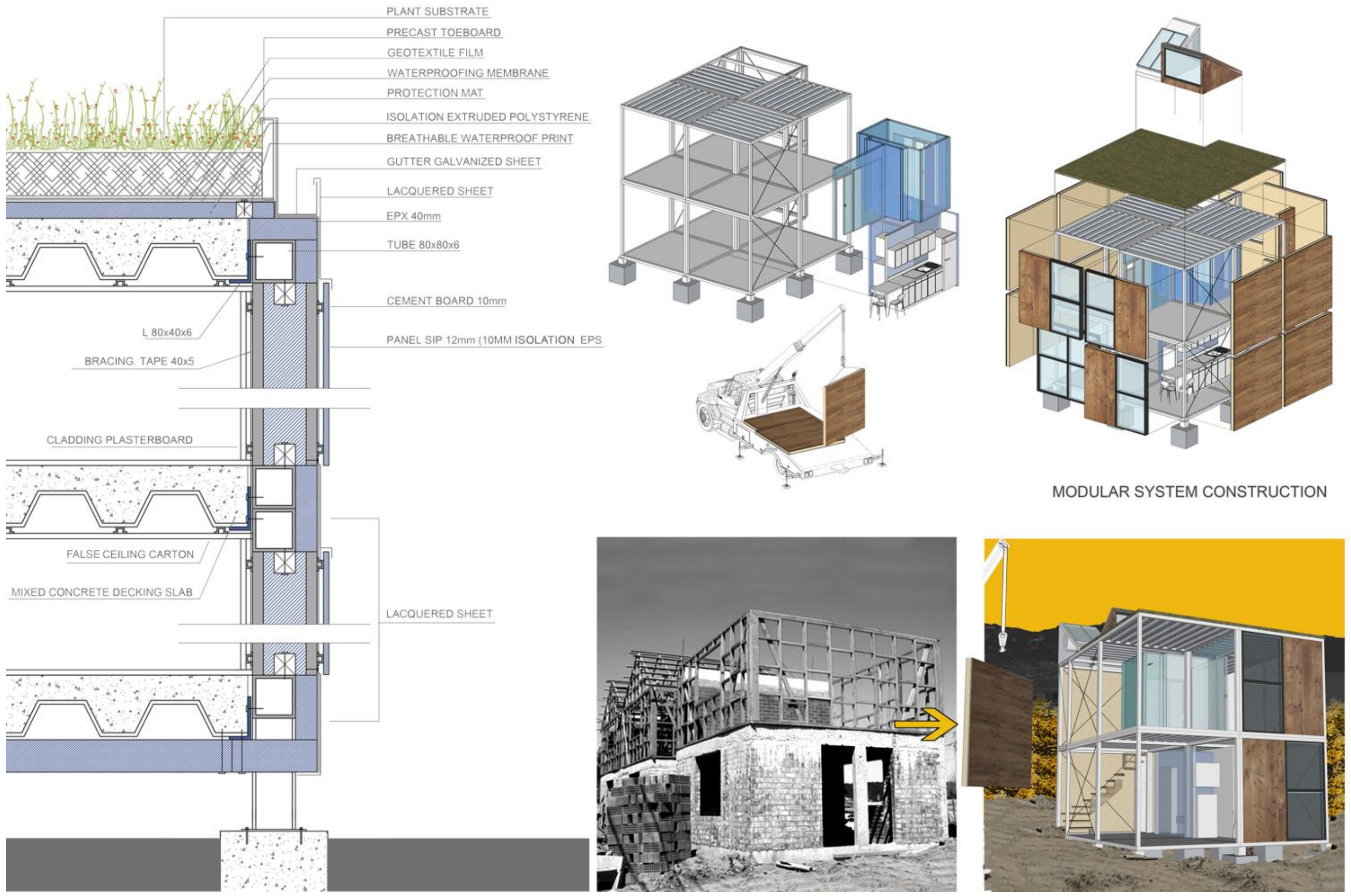

Figure 4. Construction modular system and the difference with the traditional construction system.

RESULTS AND CONCLUSIONS

About the architectural proposal for the CASA+ housing model previously described (2 floors and 60m2); simulations were performed with specific software. All simulations were performed with a north orientation of the main facade. In all the studied cases, sharp declines in energy demand were obtained when comparing data between materiality referred to the Thermal Regulation and the proposals. Several starting decisions for the architectural design, and the choice of materials, have been predicted from previous investigations, such as increased insulation of the envelope to suitable U values, the use of inner thermal inertia, or the dimensioning of the windows in approximately 20% of the floor surface (Fig.5). From the results obtained in the simulations, the following conclusions can be drawn:

- The CASA+ prototype, simply by being architecturally designed according to the climatic conditions, obtains, using an envelope according to the Thermal Regulation for a comfort range between 18°C and 27°C, an energy demand of 115-100kWh/m2, lower than homes built today in Chile in the area on the research, which ratio ranges from 190kWh/m2 to 143kWh/m2, according to data provided from previous research.

- The CASA+ prototype developed with an improved thermal envelope in relation to Thermal Regulations, shows a decrease in energy demand of 70-75%, and fits into the category A of energy efficiency as it shows savings exceeding 55% over the reference building according to TR. This improvement increases up to 75-80% in the case of semi-detached houses, with a common dividing wall, and 80-85 % in the case of terraced houses matched by two sides. Improving energy efficiency in detached and semi-detached houses is between 20-22% in the case of semi-detached houses and between 30-32 % for terraced housing. The values in the lower ranges, between 47 and 16 kWh/m2 are values already adjusted to acceptable quality standards in developed countries.

THERMAL ANALYSIS OF TRADITIONAL HOUSINGS

WALLS W/m²ºC	WINDOWS W/m²ºC	% NORTH WINDOWS	% SOUTH WINDOWS	THERMAL MASS 10cm	AGGREGATION	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement	KWh m²/year	% improvement
1,7	5,8	30	20	No	HOUSING WITH THERMAL CURRENT REGULATION (1)	147		107		69		143		111		81		140		115		91	
0,8	3	30	20	No	HOUSING IMPROVED WITHOUT THERMAL MASS (2)	91	39%	70	35%	50	28%	87	39%	71	36%	55	33%	75	46%	67	42%	60	34%
0,8	3	30	20	Yes	HOUSING IMPROVED WITH THERMAL MASS (3)	76	49%	54	49%	33	51%	71	50%	55	51%	38	53%	65	54%	53	54%	40	56%
0,8	3	60	10	Yes	OPTIMIZATION OF NORTH WINDOWS SURFACE AREA (4)	58	61%	34	69%	20	71%	54	63%	42	62%	29	72%	51	64%	41	65%	34	63%
0,8	3	60	10	Yes	% WINDOWS AREA WITH REGARD TO HOUSING FLOOR AREA (4)	22%		21%		20%		19%		17%		17%		22%		21%		20%	

Figure 5. Energy saving simulations.

Another quality of the prototype is to achieve these standards with a sufficiently tight economic investment in cost-benefit ratio. The budget studies show that the construction of CASA +, considering the plot, represents an impact of 57USD/m2 , which fits into the average cost, that is at the 65USD/m2 . Major savings could be achieved by improving the execution times at the workplace, increasing prefabrication, which could lead to improvements in finished or increscent of the floor area.

The first CASA+ prototype is currently in the pre-project implementation phase. The interest of the property market on the proposal, leaves the door open to a new phase in which, if it is possible to combine synergies and attract the adequate funding, the completion of a construction project. Its development would be made in UBB to assess the complexity of construction, cost and assay, and above all, to make the energy monitoring over a prolonged period of time, so that the feasibility of the proposed scale can be demonstrated. The research methodology allows to be extended to other climates of the region and other Latin American socio-economic realities, with a previous study of local peculiarities, both in terms of climate and the constructive development. The system, currently limited to detached or grouped house, could be developed using the same methodology for high-rise housing. The private sector participation in the development of the system is considered crucial by being involved in the technological development and financial feasibility, as well as the legislature, by facilitating the exchange of improving energy efficiency by equivalent improvement in the construction and architectural quality of the middle and lower class's homes.

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